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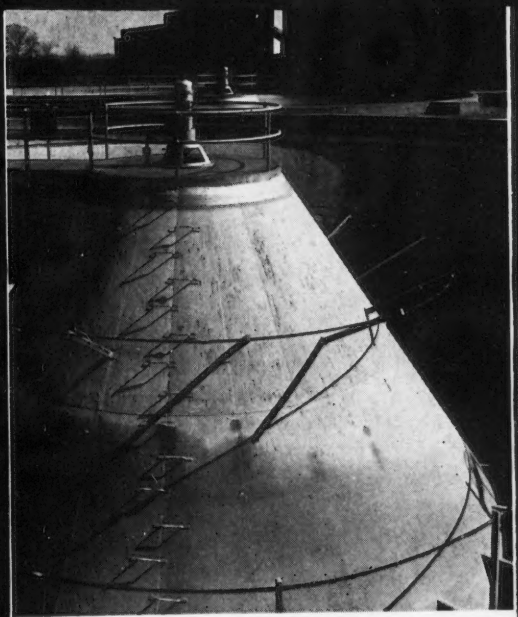
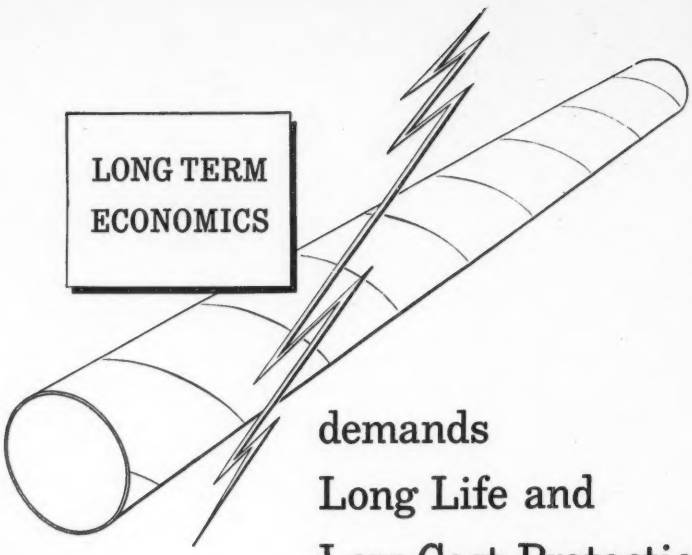


Cathodic Protection in Water Purification



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Corrosion

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NATIONAL ASSOCIATION OF CORROSION ENGINEERS

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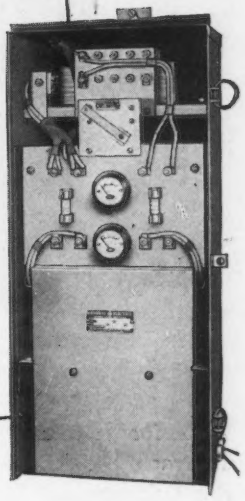

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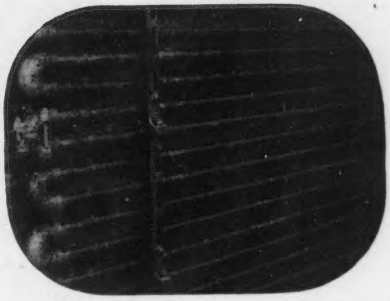

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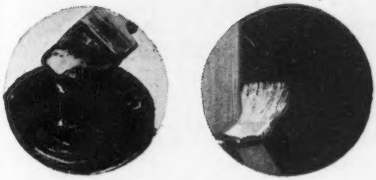

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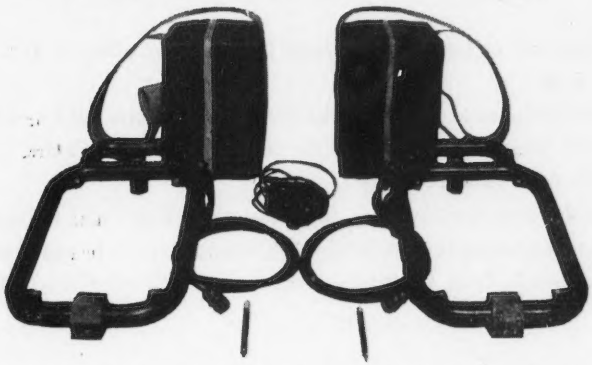

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Cathodic Protection As a Corrosion Control Method Applied to Steel Surfaces Submerged in Water

By L. P. Sudrabin

Chemical Engineer, Electro Rust-Proofing Corporation, Newark, N. J.

THE VAST AMOUNT of fundamental work conducted in the field of corrosion control since W. R. Whitney (1) first postulated the electrochemical theory of corrosion in 1903 has provided the corrosion engineer a relatively clear conception of the "tools" with which he can prolong the life of steel structures against aggressive water environments. Metal wastage in waters containing dissolved oxygen and having a pH in excess of 4.5 usually is not uniform over the submerged surface, but instead is characterized by randomly located pits of various sizes and shapes, depending on environmental factors, with the adjoining areas showing very little or no attack. This local cell action type of attack results in the development of leaks in steel vessels confining water, or in the failure of structural steel members, even though most of the original metal is intact. The economic and functional problem of repair or replacement has stimulated search for means whereby the corrosion of metal under water can be mitigated.

The methods of underwater corrosion control available consist of either or a combination of: (a), the use of protective coatings; (b), conditioning of the water; and (c), electrolytic means. Often the proper combination of these methods will provide the most satisfactory procedure of corrosion control.

The electrolytic corrosion control method best known as cathodic protection is obtained by projecting a direct current flow from an auxiliary electrode (anode) in the corroding media (electrolyte) to the submerged metal surface (cathode), whereon cathodic processes are induced.

Cathodic protection is complete only when the cathodic processes occur on the protected surfaces and all the anodic processes required to maintain such a condition have been transferred to an auxiliary anode properly positioned in the corroding media. These cathodic processes tend to leave a predominance of hydroxyl ions on the metal surface through the preferential reduction of any oxygen molecules reaching the metal-water interface

$$(1)\quad \tfrac{1}{2}\,O_2 + 2e + H_2O > 2\,OH^-$$

and by the reduction of the hydrogen ions resulting from the dissociation of water

$$(2)\quad \begin{array}{c} 2H_2O \rightleftarrows 2OH^- + 2H^+ \\ \qquad\quad + 2e \\ \qquad\quad \downarrow\ \uparrow \\ \qquad 2H^\circ \rightleftharpoons H_2\uparrow \end{array}$$

Although cathodic protection was used more than 120 years ago by Sir Humphrey Davy (2) when he thought of a metal that "If it could be rendered slightly negative, the corroding action of sea water upon it would be null;" the development of the practical application of the principle until recent years has been slow.

Davy obtained the protective current flow through galvanic action by coupling the more electro-negative metal (anodic) zinc with the less electro-negative metal (cathodic) copper or iron to be protected. The area protected by a single zinc plate was limited by the relative position, difference in the potential existent between the two metals coupled, specific resistance of the water and the protective current density requirements.

Around 1910, Cumberland (3) used a motor generator as an external source of protective current which was applied from insulated anodes within the water box of a surface condenser. The potential between the anodes and the surfaces to be protected could be regulated so as to obtain the current flow required. A tendency towards applying a fixed current density for all corrosion environments, and the complexity of properly distributing the protective current flow over the tube and drum surfaces of boilers and surface condensers on which cathodic protection was being applied, apparently resulted in only a few sporadic instances of effective corrosion control.

In 1936, cathodic protection was first effectively applied as a corrosion control method to the underwater surfaces of a standpipe in the municipal water system of Dayton, Ohio. Since that time, several thousand installations have been made on industrial and municipal water storage tanks, hot water generating tanks, water and sewage clarifier mechanisms, sludge blanket filtration type cold process softeners, deep well column pipe and casings, etc. These installations consist of small diameter electrodes immersed in the water, insulated from the metal surface to be protected, and designed in a pattern to distribute properly the protective current flow. A rectifier, usually of copper oxide or selenium type, with provision for voltage adjustment over a wide range, is used to drive the required protective current flow.

The wide variation experienced in the characteristics of the corrosion environment, operation and geometric configuration of the submerged structures to be protected has emphasized the need to establish the factors influencing the protective current density requirements, the electrode design and material, the power supply, etc.

Protective Current Density

Although the conditions creating the potential differences over the metal surface which result in electrochemical corrosion (4) and the mechanism of the cathodic protection principle (5, 10) applied to stifle this corrosion process have been well established, relatively little attention has been given to the rate processes which influence the protective current density required for cathodic protection.

It has been found in practice that the over-all current density require-

ments for the protection of steel in a quasi-stagnant water environment usually range from 0.2 ma. to 20 ma. per sq. ft. of submerged area, although in some instances a higher protective current density than 20 ma. square foot is required. The actual current density requirements can be anticipated from an interpretation of environmental factors, such as: the dissolved oxygen concentration and insoluble salt depositing tendencies of the water, velocity, temperature, condition of applied surface coating, the presence of continuous barrier layers, and the operating conditions which influence any of the previously mentioned factors.

Among his many corrosion experiments Davy (2) observed that zinc was not required to protect copper or steel in sea water deprived of air by boiling or exhaustion. He found that the oxygen of the air was the active agent and concluded that in its absence the need for protection was negligible. These observations in a very simple way suggest the importance of dissolved oxygen upon both the corrosion rate and the current requirements for cathodic protection against a water environment.

In 1913, Clement and Walker (6) of the U. S. Bureau of Mines reported their studies, conducted on the application of cathodic protection to bare steel surfaces in contact with acid mine waters. They observed that in 0.1 normal sulfuric acid the protective current density requirement tends to increase with an increase in dissolved oxygen concentration, and also with an increase in stirring.

Studies (10) have been made by our company to establish the significance of the dissolved oxygen concentration of a non-scale-forming water, in which the corrosion rate would be primarily under oxygen control, upon the current density required to protect a bare steel surface. Rectangular glass cells were used to confine the corroding media in which a 2x4x1/16-inch hot-rolled steel plate cathode was suspended vertically between two aluminum plate anodes. By applying increasing current densities to a series of the steel plate cathodes in test cells confining a water containing a fixed dissolved oxygen concentration, the protective current density was established for the environment by visually examining the test specimen and by weight loss measurements. An effort to use potassium ferricyanide as a specific reagent for the ferrous ion created by the anodic process in electrochemical corrosion, to indicate the minimum protective current density as used by Evans (7), proved to be unsatisfactory, since the protective current density requirements appeared to increase markedly with an increase in the concentration of the reagent.

The water in the test cell was slowly displaced with water containing the fixed oxygen concentration, so as to minimize the effect of the cathodic reduction processes upon the oxygen in the bulk of the water and any effect resulting from the presence of aluminum ion. The studies were conducted with three types of non-scale-forming water: (1), deironized Westport, Conn., water; (2), 0.1 normal sodium chloride solution; and (3), in normal sodium chloride solution.

Varying the salt concentration and the pH between 5.5 and 8.0 with a fixed dissolved oxygen concentration did not influence the current density

requirements appreciably. Other studies using the log current density-potential technique, suggested by Evans, Bannister and Britton (8), and by Ewing (9), showed some promise in solutions having the higher salt concentrations.

When the temperature and velocity of the corroding media are held constant, the protective current density requirements for a bare metal surface exist in approximately a linear relationship with the dissolved oxygen concentration. This is illustrated by line A-A in Fig. 1. Variations in temperature or velocity markedly alter the slope of this relationship.

With natural waters, in the absence of any dissolved oxygen, a small protective current flow is required to compensate for hydrogen depolarization. This current density requirement tends to increase with decrease in pH until at a pH of about 4.5 the current density requirements are essentially under hydrogen depolarization control.

Through further investigation, it was discovered that, in a $CaCO_3$ saturated water, a horizontal bare metal surface covered with a thin continuous layer of 25-50 mesh calcium carbonate had very low protective current density requirements. The current density requirements under these conditions are only slightly influenced by the dissolved oxygen concentration. An identical layer of 25-50 mesh acid-washed sand in a water containing no scale-forming salts proved to be equally effective. In large diameter standpipes it has been practical to cover the floor area with a thin, continuous barrier layer of limestone, thus tending to reduce the over-all current and power requirements and to simplify the electrode design, since only the sidewalls would require the higher current densities. Our company is using the barrier layer principle in many water storage tanks effectively.

Line B-B in Fig. 1 illustrates in a general way the effect of a barrier layer upon current density requirements. Whereas on a bare metal surface at a dissolved oxygen concentration of "O" the protective current density requirements correspond to "a," the use of a thin barrier layer of limestone over the bare metal would tend to reduce these requirements to "b." Apparently the barrier layer is effective in preventing the cathodic process products from leaving the metal surface, and in obstructing the movement of corrosion stimulating constituents to the metal surface from the bulk of the water.

Since the cathodic processes induced by cathodic protection generally result in creating a predominance of hydroxyl ions on the cathode surfaces, there is a tendency for the scale-forming salts in the water to be precipitated as calcium carbonate or magnesium hydroxide. All waters do not possess the same scale-forming tendencies, and in some instances a very high current density is required to cause precipitation of the scale-forming salts. The Langelier Saturation Index (11) provides an indication of the scale-forming tendencies, although at low hardness and alkalinity concentrations, the Index offers very little criteria in establishing the current density required to cause precipitation.

Figure 1 illustrates two critical current densities, C_a and D_a, at which the deposition of scale-forming salts may occur. Initially, after the pro-

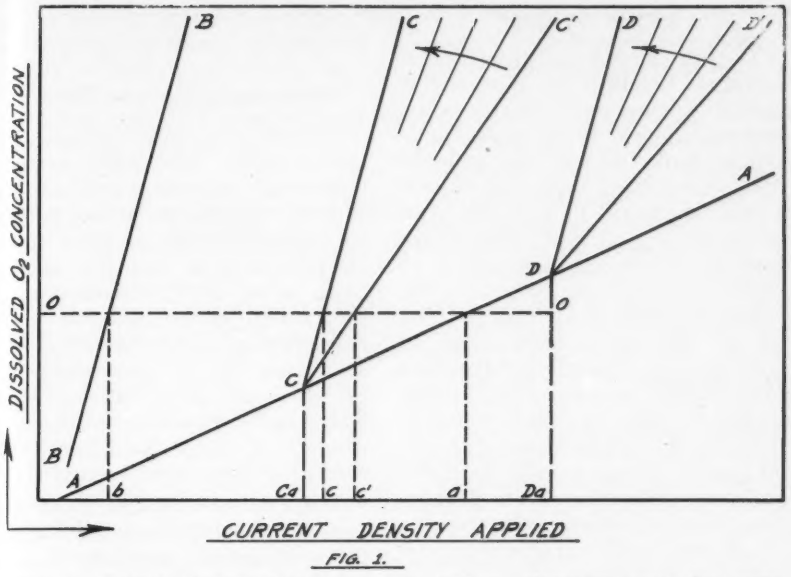


Figure 1—General diagram illustrating some factors influencing protective current density requirements. A-A: Bare metal surface. B-B: Barrier layer. C-C and D-D: Deposit of scale-forming salts precipitated at c.d.'s, Ca and Da.

tective current is first applied, the deposition will be extremely thin, having very little effect upon the diffusion rate of oxygen molecules to the metal surface. However, as the deposition builds up it becomes more effective, tending to reduce the current density requirements. Example: At dissolved oxygen concentration "O," the current density requirements for condition C-C' would be "c'". As the film thickness increases, the protective current density slope approaches C-C and the protective current density requirement is reduced to "c." In this case a current density of at least C_a must be maintained, or else the deposition formed will tend to redissolve slowly. From this illustration, it can be visualized that the protective current density requirements will decrease as the length of time that cathodic protection is applied increases.

Cathodic protection can be complete without the deposition of scale-forming salts. For example, at a dissolved O_2 concentration of "O," a current density of "a" would be required to protect a bare metal surface, whereas a current density of "D_a" may be required to cause deposition of scale-forming salts.

The nature of the scale-forming salts encountered in practice will be described later.

The presence of relatively continuous films of oil, silt and corrosion products tend to reduce the protective current densities that are ordinarily required for bare metal surface.

Surface Coatings

The use of cathodic protection to police the holidays which develop in coal-tar enamel or asphaltic surface coatings applied to the pipe line in contact with soil has been common practice for many years. Coatings of a coal-tar enamel or asphaltic type, or the drying oil type, such as red lead and basic lead chromate, all tend to minimize the protective current flow required for cathodic protection. The combination of applied coatings and cathodic protection often should be considered in establishing the most satisfactory protection procedure. Although the drying-oil type of paint is usually quite thin and permeable to moisture penetration, it is fairly effective in reducing the current density requirements for complete protection. This is true, even though the coating is in very poor condition and by itself would afford little or no protection. There are instances where this type of coating, covering the submerged surfaces of tanks to which cathodic protection was applied 10 years ago, is still effective in reducing current requirement even though the coating is badly blistered. There is a tendency for the increased pH produced on the metal surface by cathodic protection to loosen the bond between the drying-oil type paint and the metal.

The coal-tar enamel and asphaltic type coatings, because of their imperviousness to moisture, high electrical resistance, and resistance to the hydroxyl ion concentration developed at the metal surface, are more effective in reducing the current requirements. However, they appear to be more susceptible to ice damage and temperature changes than the drying-oil type paints.

Electrode Design and Material

In order to protect a large standpipe, clarifier mechanism, or other steel structure submerged in an aggressive water environment, particular attention must be given to the electrode design and the material used, so as to distribute properly the current at the optimum power consumption, without introducing anodic activity products into the water which would be objectionable, or which in the particular environment would tend to increase the protective current density requirements.

The electrode design primarily consists of establishing the number, diameter, length, configuration and the material. Submerged steel structure appendages, or the risers of elevated water tanks, require electrodes along their entire length. A controlled current flow must be applied to provide protection to such areas.

Since the specific resistance of waters normally encountered ranges from around 500 to 25,000 ohms per cubic centimeter, the number, length and diameter of the electrodes are of particular significance in controlling the overall resistance from the anode configuration to the tank walls. The power costs must be considered in the electrode design, without losing sight of distributing properly the protective current flow.

The electrode materials used in cathodic protection are of two general types: (1), Sacrificial; (2), Non-sacrificial.

Sacrificial electrode materials tend to be consumed in amounts equiva-

lent to the current flow from their surfaces.

Table I illustrates the electrochemical equivalents of some of the sacrificial type metals considered for use as electrode materials.

TABLE I

Electrochemical Equivalent of Some Metals (Sacrificial)

Anode Material	Weight of Material Consumed per 26.8 Ampere Hours of Current Flow Grams	Ampere Hours per Pound of Hours of Material
Aluminum	9.0	1352
Copper	31.8	382
Iron	27.9	436
Zinc	32.7	372
Nickel	29.3	416
Magnesium	12.2	997

The stainless steels generally lose their passive properties when used as anodes and often approach the behavior of ordinary hot-rolled steel in practice.

Because of its light weight, ease of assembling into long lengths, and high electrochemical efficiency, aluminum lends itself to use as sacrificial anode material in cathodic protection. The degradation product tends to adhere to the metal core and very little of the white aluminum floc is introduced into the water. One of the limitations of steel electrodes is the formation of ferric hydroxide, some of which migrates and deposits on the cathodic metal surface, often leading to a misinterpretation of the effectiveness of cathodic protection by its presence.

Non-sacrificial electrode materials are not appreciably consumed by the flow of current from their surface. However, the anodic process which does occur on their surfaces, in natural waters low in chlorides, is usually the production of oxygen gas in amounts equivalent to the current flow. The non-sacrificial anode materials include: gold, platinum and, to a certain extent, graphite. In closed water systems, or in certain environments where the dissolved O_2 concentration of the water is low, the oxygen introduced at the anode will tend to increase the protective current density requirements. Graphite has a tendency towards brittleness and can be assembled only in relatively short lengths. In water, which offers no support, the graphite particles tend to slough off from the core.

In a closed hot-water system, the corrosivity of the water entering the distribution piping would be influenced by the O_2 added from a non-sacrificial anode in the hot-water generating tank, whereas with a sacrificial anode the cathodic reduction of the dissolved oxygen and increase in hydroxyl ion concentration occurring on the tank wall tend to reduce the corrosivity of the water.

Since the diameter of the platinum wire which can be economically justified is small, the I. R. drop along its length offers limitations to the proper distribution of current. Studies made in water tanks, to establish the effect of the electrode diameter upon the resistance between an anode configuration and the tank wall, have shown that the resistance from a group of No. 24 Birmingham Wire Gage platinum wire electrodes is approximately two to three times that from an identical group of ¾-inch diameter electrodes. Thus it is necessary to position properly in the electrode design a group of platinum wire electrodes having at least three times the overall length of the larger diameter electrodes, in order

to obtain the required protective current flow with no increase in power consumption, neglecting any effect of the non-sacrificial anode in increasing the current density demand. Platinum clad wire or rod overcomes the I. R. drop and the diameter limitations, but is costly.

In the design of cathodic protection equipment, the problem of ice formation must be considered. It is difficult to predict the behavior of ice within a tank. Frequently the ice moves in the manner of a piston up and down the tank with water level changes. In other instances, the ice breaks up and by churning action damages the electrodes suspended within the tank. The ice formation usually begins on the submerged side walls of the tank and gradually bridges across the surface of the water. Studies previously reported by the author (12) indicate that when a metal surface is covered with ice, the corrosion rate is negligible. The moment the ice has melted, corrosion activity begins, increasing to a maximum in the summer months and then decreasing to a minimum when ice forms in the fall. Since applied surface coatings are damaged by ice, the logical period to apply protective maintenance to a tank is in the early spring.

The best practice is to apply cathodic protection as soon as the ice has melted. The electrodes usually can be installed without emptying the tank contents. Enough electrode stock should be provided so that it will be nearly all consumed during the "corroding season." A new set of electrodes is provided at the beginning of the next "corroding season."

Galvanic Electrodes

The use of galvanic anodes of aluminum, zinc or magnesium appears to be feasible when the specific resistance of the corroding water media is very low, and when the protective current density requirements are low. Otherwise, the relatively small voltage driving force available will require a very complicated and large electrode configuration to obtain the protective current flow required.

Applications

A. *110,000 Gallon Standpipe, Grafton, Mass.*

A review of the corrosion case history of a 110,000 gallon standpipe in Grafton, Mass., which is used to store a typically aggressive New England water, illustrates an instance of the effectiveness of cathodic protection. The standpipe was constructed of wrought iron plate more than 45 years ago. During the last 15 years, the wastage of metal by corrosion has resulted in an average of two to three leaks each year developing through the lower two plates of the tank.

In 1935, a cold coat of an "asphalt emulsion" was applied to the tank surface. However, the ice in the following winter damaged the coating with the result that the two to three leaks yearly continued to develop. Patching the exposed surfaces with a drying-oil type paint did not stop the continuance of leak development. In 1943, cathodic protection was applied, with the result that no further leaks have developed in the succeeding years. The exposed areas, from which the previously formed corrosion product had been removed by

ice movement in the winter of 1943-4, show no further activity in the form of tuberculation during the "corroding season" of 1944 and 1945.

Approximately 95 percent of the submerged metal surface is still covered by the "asphalt emulsion." Though it alone did not stop the development of leaks, it has been effective in reducing the current flow required for protection many fold, compared to that which would have been required for a bare metal surface in the same environment. The protective current applied to this tank was about 1.5 amperes.

The electrodes are removed from the tank each fall and reinstalled each spring, as soon as the ice has melted.

An interesting picture is provided by a comparison of some of the pit depths with the metal thickness, which tends to establish the effectiveness of the protective system used on this tank. Measurement of the bottom wall sheet thickness indicated the wrought iron sheet to range from 0.275 inches to 0.300 inches. A measurement of the pit depths on the bottom sheet where the maximum pitting occurred showed the following depths:

TABLE II

Grafton, Mass. Standpipe—Pit Depths 1945

Inches	Inches
0.260	0.265
0.230	0.294
0.149	0.254

It is clearly evident that in some areas the metal thickness is only a little thicker than a sheet of paper.

The water stored has the following analysis:

TABLE III

Grafton, Mass.—Water Analysis

Total Dissolved Solids	66 ppm
Chlorides	6 ppm
Total Hardness	27 ppm
Total Alkalinity	23 ppm
pH	6.0
Dissolved Oxygen	Approaches Saturation

Although no scale-forming salts were deposited on the exposed areas, these areas did have a healthy oxide film.

B. *Mahoning Valley Sanitary District Clarifier.*

In 1942, cathodic protection was applied to the No. 4 95-foot square Dorr Traction Clarifier on which severe attack in the form of pits was observed on the rake arm structure and the center drum. The initial installation was limited somewhat in effectiveness by the electrode design. However, a redesign in 1944 of the electrode configuration, by positioning the electrodes parallel along the full length of the rake arm structure and controlling the protective current flow from each electrode, effectively reduced the corrosion. The structure originally had been painted with two coats of red lead.

An inspection on July 2, 1945, of test angles on the cross arms of the structure, which were wire-brushed after the previous inspection on June 13, 1944, showed no evidence of corrosion activity. A record of pit depth progress made by the Mahoning Valley Sanitary District (13) is shown in Table IV.

The eight-fold reduction of penetration rate obtained with the revised electrode design and operation, along with absence of corrosion ac-

tivity observed on a conditioned member, illustrates the effectiveness of cathodic protection. The

TABLE IV

Penetration Rates on Rake Arm Mechanism, Mahoning Valley Sanitary District

Point	Penetration, Inches		Rate, Inches	
	6–13–44	7–2–45	In 12.5 Months Preceding 7–2–45	In 7 Months Preceding 6–13–44
1	.092	.090	0.000	0.004
2	.149	.149	0.000	0.003
3	.129	.131	0.002	0.007
4	.118	.118	0.000	0.015
5	.115	.116	0.001	0.007
6	.124	.126	0.002	0.014
7	.102	.102	0.000	0.000
8	.176	.179	0.003	0.007
9	.140	.143	0.003	0.006
10	.134	.134	0.000	0.002
11	.100	.097	0.000	0.004
12	.118	.118	0.000	0.008
13	.130	.131	0.001	0.000
14	.101	.104	0.003	0.006
15	.107	.115	0.008	0.003
16	.167	.169	0.002	0.003
17	.126	.126	0.000	0.007
			0.025	.106
			17x12.5 = .00012 per Mo.	17x7 = .0009 per Mo.

treated surface water confined within the clarifier mechanism has approximately the following analysis:

TABLE V

Mahoning Valley Sanitary District—Water Analysis

Total Hardness	85.0 ppm
Total Alkalinity	43.0 ppm
pH	10.3
Dissolved Oxygen	Approaches Saturation

C. *Spaulding Precipitators—Springfield, Ill.*

Another type of structure to which cathodic protection can be applied is a sludge blanket filtration type of cold process softener. (Figure 2.)

This type of cold process softener was first used in Springfield, Ill. More than 10 years ago, three precipitators were constructed to soften and clarify the city water supply, taken from the impounded reservoir, Springfield Lake. Although corrosion attack of the steel cone of the precipitator was not anticipated, because of the scale depositing tendencies of the water being softened, actual penetration of the cone occurred within about six years.

The cones had been painted at regular intervals with a drying-oil type paint. In 1944 cathodic protection was applied to one of the precipitators in order to establish the effectiveness of cathodic protection. Examination of the submerged surfaces of the precipitator in 1945 indicated complete control of corrosion. In October, 1945, cathodic protection was applied to the remaining two precipitators. Figure 2 illustrates one of the latter installations.

Two ring electrodes outside the cone, and another group of two ring electrodes within the cone, are used to distribute the protective current flow. Other electrodes are positioned outside and on the inside of the flume. The electrodes have been designed for three-year life. The protective current flow is controlled to each group of electrodes from one rectifier, in order to provide the proper distribution of current.

The surface water to be treated approaches saturation with dissolved oxygen. Leaving the treatment plant it has a pH of 9.9 and a total hardness of 89.0 ppm.

D. *150,000 Gallon General Service Tank, Dayton, Ohio.*

In 1936, one of the first cathodic protection installations was made on a new 150,000 gallon elevated general service tank at the Miller's Ford Station of the Dayton Power &

Light Company, Dayton, Ohio. The tank had been covered wtih two coats of red lead during construction. Recent inspection showed the red lead coating to be badly blistered, but very little actually had dropped off from the sidewalls. No corrosion activity has been observed, and all the metal areas exposed to the water are covered with a white deposit. The water stored is deep well water which has a tendency towards readily depositing scale-forming salts with a low applied current density. The water analysis is shown in Table VI.

TABLE VI
Miller's Ford Well Water Analysis

Calcium	80 ppm
Magnesium	34 ppm
Phenolphthalein Alkalinity	0 ppm
Methyl Orange Alkalinity	301 ppm
pH	7.4
Total Dissolved Solids	389 ppm
Total Hardness	342 ppm
Dissolved Oxygen/Liter:	
At Surface in Tank Bowl	1.01 c.c.
Bottom of Bowl	.50 c.c.
In Riser	.084 c.c.

The dissolved oxygen concentration measured at various depths of the tank indicates that oxygen is entering the water system through the air-water interface in the tank.

Table VII illustrates the chemical nature of the salts deposited on the bare metal surface of this tank.

The composition of the solution accumulating under the paint blister also proved interesting. Table VIII may be compared with the composition of the bulk of the water shown in Table VI.

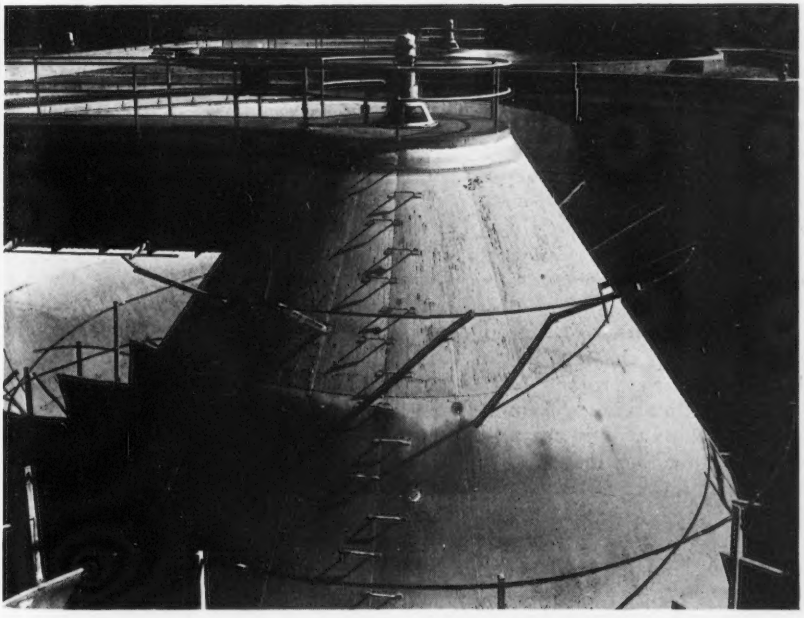


Figure 2—Electrode design used to distribute the protective current flow over the submerged surfaces of a Spaulding Precipitator, Springfield, Ill.

A 100,000 gallon tank built in 1931 at the Dayton Power & Light Co., Central Steam Heating Plant, con-

TABLE VII
Nature of Deposited Salts

	Percent
SiO_2	0.20
CaO	46.5
MgO	11.2
R_2O_3	0.20
CO_2	36.6
Ig. Loss	41.6
SO_3	Trace
Cl	Trace

fining similar water, and operating in a manner comparable to the previously described tank, developed leaks in the bowl in 1939. The leaks were welded at that time, and cathodic protection was applied. No further corrosion activity has been observed.

E. *City of Detroit Hot Water Generating Tank.*

In spite of the use of various coatings recommended for steel surfaces in contact with hot water, pits exceeding 3/16 inch were generally distributed over the submerged surfaces of a 1400 gallon hot-water generating tank used in the City of Detroit Water Board Building. The original shell thickness of the tank was ¼-inch.

The inner surface of the tank was sandblasted in the summer of 1945 before cathodic protection was applied. An aluminum electrode is being used to distribute the protective current flow. An inspection of the tank in March, 1945, showed the presence of some scale-forming salts deposited on the walls of the pressure tank and no evidence of any active corrosion attack. The metal surface had a continuous healthy oxide film.

TABLE VIII
Water Under Paint Blisters

Phenolphthalein Alkalinity	1158 ppm
Methyl Orange Alkalinity	3910 ppm
pH	10.3

The City of Detroit water is stabilized with calcium carbonate. Although the make-up water to the hot-water system is practically saturated with dissolved oxygen, the dissolved oxygen within the tank varies between 2-4 ppm. Since the hot water system is of the circulating type the oxygen is cathodically reduced on the heating tank walls by the protective current flow and in the piping by the corrosion current flow.

Conclusions

Cathodic protection is being applied to several thousand structures such as water tanks, clarifier mechanisms, and hot-water generating tanks in contact with aggressive water environments.

Protective current density requirements can be rationalized from the proper interpretation of dissolved oxygen concentration and scale depositing tendencies of the water, nature of the surface coating, the effectiveness of a barrier layer, the velocity and temperature. Operating conditions which influence any of the factors previously mentioned must be interpreted properly in order to apply cathodic protection most effectively. Often surface coatings used in conjunction with cathodic protection will provide the most effective over-all corrosion control.

Many operating limitations encountered with non-sacrificial anodes encourage the use of sacrificial anodes, of which aluminum appears to be the most promising.

In regions where ice is encountered, adequate electrode stock should be provided to last during a "corroding season;" the "corroding season" being the period when ice is not present in the tank.

Galvanic anodes appear to be feasible where the specific resistance of a water and the current requirements are low. Cathodic protection will be effective if an adequate current flow is distributed properly over the surfaces submerged in the corroding water.

References

1. Whitney, W. R.; Jour. A.C.S. **25**, 394, 1903.
2. Davy, H.; Phil. Trans. 273-81, 1824.
3. Cumberland, E.; Engineering, 101, 313, 1916.
4. Mears, R. B. and Brown, R. H.; Ind. and Eng. Chem. **33**, 1001-10, 1941.
5. Brown, R. H. and Mears, R. B.; Trans. Electrochem. Soc., **81**, 455-81, 1942.
6. Clement, J. K. and Walker, L. V.; Bureau of Mines, Tech. Paper No. 15, 1913.
7. Evans, U. R.; Metals and Alloys **2**, No. 3, 62-4, 1931.
8. Evans, Bannister and Britton; Proc. Roy. Soc. **131A**, 355-375, 1931.
9. Ewing, S.; Proc. A.G.A.; 22, 613-22, 1940.
10. Sudrabin, L.; Proc. 5th Annual Water Conf. Engr's. Soc. Western Penn., Oct., 1944.
11. Langelier, W.; Journal A.W.W.A., **28**, 1500-21, 1936.
12. Sudrabin, L.; Water Works and Sewerage. 92, 11, 51, 147, 1945.
13. Fawcett, L; Mahoning Valley San. Dis. Report, July, 1945.

October Cover

The cover illustration on this issue shows the same view as pictured on page 185 of this article, demonstrating cathodic protection applied to submerged surfaces of a Spaulding Precipitator at Springfield, Ill. This picture shows the electrode design used to distribute the protective current flow over the surface.

Chemical Treatment of Distillate Wells—Practical Aspects

By T. S. Bacon

Lone Star Producing Company, Dallas, Texas

OUR COMPANY was faced with the problem of corrosion of distillate wells in the summer of 1942. Serious corrosion in several wellheads in the Opelika field was observed at that time, and the necessity for a solution to the problem was very apparent.

Field experiments on the chemical treatment of distillate wells to reduce rate of corrosive attack were initiated in December, 1942. These experiments have been continued since that time and several conclusions have been reached regarding methods of injection, and also regarding the effects of inhibitors on corrosive attack in this particular field. Although many of the results are entirely negative, the field technique has been improved materially from the early days and some discussion of present day techniques might be in order.

There are three primary problems that must be solved before any chemical treatment is successful in the field. These problems are: (1), what to inject; (2), how to inject the desired chemical; (3), how to determine the effects of the chemical after injection.

The perfect inhibitor is entirely useless in the field until it has been properly injected into the produced fluid stream. Two general methods of injection have been used. The first of these is the use of the ordinary liquid pump, and the second is the use of the lubricator, or pressure storage tank, in which the pressures are equalized above and below the liquid to be injected. A third method of injection of solids through properly designed equipment has not been used by the Lone Star Producing Company.

The lubricator type of injector appears to be more reliable than the pump type of injector, and is preferred for injection of rather small daily volumes of treating solution. The lubricator has no moving parts and is extremely simple mechanically. It appears desirable to install a strainer on the liquid line ahead of the flow control valve to prevent clogging of the valve. Lubricators are subject to freezing in the winter time, particularly if water solutions of the treating chemicals are used, due to formation of hydrates at the elevated pressures that must be employed. Lubricators having liquid capacities in excess of 20 to 50 gallons become extremely bulky and rather expensive due to the heavy construction required to withstand the operating pressure. For this reason, pumps are preferred when required daily deliveries are in excess of 50 gallons per day per well.

Chemical pumps designed to deliver from 20 to 150 gallons a day against pressure up to 5,000 pounds per square inch have been used in

the field. Pumps of the smaller capacities have been driven by expansion of gas. Pumps of the larger capacities have been of the engine-driven type. All chemical injection pumps used have been of the plunger type, preferably with dual valves on both suction and discharge. The pumps we have used to date give trouble when handling dilute aqueous solutions of the various inhibitors. This is largely confined to valve trouble, but packing trouble also enters into the picture to an appreciable degree. Pump trouble is lessened very materially, and in fact so much so as to become relatively insignificant, when oil-soluble inhibitors are used in a solution of mineral seal oil. A gasoline-engine driven pump, using a small-air-cooled gasoline engine, is preferred for wintertime operation when water-soluble inhibitors are used. The exhaust heat and the cooling air from the engine can be used to maintain a satisfactory operating temperature of the solution to be injected. However, the cost of servicing any chemical pump in the field is very appreciable.

Protection of sub-surface equipment may be obtained by injection of the treatment through the casing, while producing the well through the tubing, or vice versa. We have followed the practice of producing high-pressure wells through tubing only. When this method of operation is followed, tubing failures that might be caused by corrosion should have no serious results. But if casing failure occurs, the well repair job becomes difficult or impossible. As no positive reliance can be placed on any method of corrosion-preventive treatment at present, it seems desirable to assume that corrosion of sub-surface equipment may continue, and therefore to produce through tubing only, as a safety precaution. We have not reworked any of our wells to assist in the use of sub-surface treatment. Returns of the injected treatment have been slow in some wells, but returns have been obtained in every well in which we have injected treatment to date.

We have not yet answered the question as to the most desirable inhibitor to use. Our experience has indicated several inhibitors that we will not use. Among these are any alkalies such as soda ash, caustic soda, or ammonia. Our experience has shown that the use of any of these alkalies in the Opelika field will result in deposition of calcium carbonate scale. The calcium enters the system in solution in the connate water, and is precipitated by the alkali. This calcium scale is deposited with such rapidity that flow of gas from the well may be seriously restricted after as little as 30 days of treatment of the well with an alkaline solution.

It was hoped that possibly the complex polyphosphates might be used with the alkali to prevent formation of the calcium carbonate scale. Field experiments using polyphosphates failed to indicate any material reduction in the rate of scale formation. Field observations indicated a material reduction in the rate of well-head equipment corrosion when alkalies were injected down the casing. However, it seems likely that the overall rate of corrosion of the sub-surface equipment would be affected only slightly by this alkaline treatment, due to the necessity for frequent reacidization of the well

tubing to remove the carbonate scale. This acidization causes some corrosion of equipment, particularly at elevated temperatures. For this reason, alkaline treatments appear to be unsatisfactory in the Opelika field.

Sodium silicate solution was injected into one well-head in the Opelika field and was found to form very heavy deposits of silica at the point of injection. Some modifications in the strength of the sodium silicate solution and in the sodium oxide silica ratio failed to eliminate this objection. An organic sulphur compound, such as used for the inhibition of hydrochloric acid in acid-treating oil and gas wells, was also used on one well. Extreme difficulty was experienced in injecting this compound due to the formation of a heavy sludge in the compound that plugged up the pump valves. As it appeared unlikely that satisfactory injection of this compound could be obtained, further attempts at this injection were discontinued, although it appeared to have some beneficial effects. Sodium nitrite has been used in one well at Opelika for several months. It was found that the use of sodium nitrite resulted in plugging the tubing string with some deposit not positively identified, but possibly calcium carbonate. Corrosion rates at the well-head when using sodium nitrite were variable and appeared to be materially reduced occasionally, whereas these rates apparently exceeded the normal value at other times.

Sodium chromate and sodium dichromate have also been used at Opelika. Extreme difficulty has been experienced in obtaining returns of the chromate ion at the well-head. Returns of the chromate at the well-head are apparently assisted materially by injection of relatively large volumes of water with the chromate. Specifically, in one well injections of 20 gallons of solution per day over a period of several months failed to reveal any returns of chromate ion at the well-head; whereas injection of 50 gallons per day or more maintained returns of the chromate ion in the well-head water samples. Well-head corrosion coupon rates were low whenever chromate returns were maintained, and were also lower than normal corrosion rates even in the absence of chromate returns in the well-head water samples. Observations of the tubing strings that have been pulled from two dichromate-treated wells show heavy deposits of reduced chromium compounds, both inside and outside the tubing string. It appears that the injection rates must be sufficient to take care of reduction of the chromate ion, and also to maintain an excess of chromate ion in the well-head water samples if completely satisfactory treatment is to be obtained. Restriction of the tubing with scale has also been observed when treating with chromate or dichromate at Opelika. However, this restriction is easily removed by reacidization of the well, and is formed less rapidly than when using alkaline solutions.

Preliminary results on the use of naphthenic acid in oil solution as an inhibitor of this type of corrosion are extremely encouraging. This inhibitor is oil soluble, and therefore hydrate troubles in the winter time are eliminated to a large degree. Small volumes, of the order of one

gallon per well per day of the acid itself, are apparently sufficient for successful inhibition in the Opelika field, so pumping troubles are largely eliminated and handling costs are low. Present practice is to dilute each gallon of naphthenic acid with 20 gallons of mineral seal oil, to aid passage of the inhibiting solution through the casing annulus. Results based on observations of well-head test coupons are extremely favorable to date in the one well which is being so treated. It is planned to expand this treatment materially in the near future to obtain further information on its effectiveness in different wells in this field. It should be recalled that the use of napthenic acid as an inhibitor was suggested by work done at the University of Texas, under the sponsorship of the Natural Gasoline Association of America, and under the supervision of Dr. Norman Hackerman. If naphthenic acid is proven to be an effective inhibitor in this field, credit should be given to Dr. Hackerman for one of the most effective developments in corrosion research on record.

Several years ago we realized the desirability of development of some short-time method for evaluating inhibitors as actually used under field conditions. Ordinary visual examination of the well-head equipment was used as the basis for evaluation when the program was initiated. This method is extremely slow, crude, and costly, and will not give quantitative results or even satisfactory comparative results between different inhibitors. Observations on untreated wells showed that rates of corrosion of well-head fittings change from time to time, apparently without correlation with well-head conditions. Therefore, observations of the effects of inhibitors based on visual examination of well-head equipment could not be conclusive. Also, significant corrosion of this equipment requires appreciable time, and a time interval of three months was set as the minimum period between inspections. It was difficult to maintain constant injection of the treatment for this interval, and, unless continued injection had been maintained, it was impossible to tell from the degree of corrosion, as observed, whether or not corrosion occurred entirely during periods when the treatment was not injected. Therefore, the development of the well-head metal test coupons has been extremely helpful in evaluating various inhibitors in the field.

The use of these coupons was first suggested by the Lone Star Producing Company, and this Company has been active in promoting interest in their use throughout the program. These test coupons are small strips of metal, approximately 1 x 8 x 1/16-inches, prepared by polishing with emery cloth before insertion in the well. They are inserted in the flow line through a bushing or flange, and installation and removal of the test coupons is satisfactorily accomplished by the ordinary field personnel at negligible cost. Our experience with these coupons has been entirely satisfactory, and we believe that excellent correlation is obtained between the rates of corrosive attack shown by the coupons and the actual rates shown by the well-head equipment. Coupons are exposed for periods of one week, two weeks, or a month as desired. The rate of corrosive attack

is determined by the weight loss of the coupon during the period of exposure. This weight loss is normally expressed in terms of inches average penetration per year to give data comparable on a common basis. In this way, relatively short-time tests of various inhibitors may be made under actual field conditions and information obtained that will give direct evaluation of the inhibitive effect at the well-head.

The inhibitive effect at other points in the system must be assumed, based on the well-head inhibitive effects. However, it seems reasonable to believe that an inhibitor that is effective at the well-head is worthy of additional field experimentation. The effectiveness of the inhibitor in tubing corrosion can be determined over long periods of time by the use of tubing caliper surveys. These surveys are expensive, and suitable equipment for making the surveys has become available only recently. However, such surveys are of extreme value in appraising the effectiveness of any inhibitor in reduction of tubing corrosion on a long-term basis.

Some thought has been given to the significance of the dissolved iron content of the well-head water samples in revealing the effectiveness of inhibitors. Our experience has indicated that the iron concentrations in well-head water samples are not necessarily a direct measure of the effectiveness of the inhibitor. Several of our non-corrosive wells consistently show dissolved iron content in excess of 100 ppm as ferric oxide in the well-head water samples. The water sample survey conducted by the N.G.A.A. also indicates many non-corrosive fields having dissolved iron content in excess of this value. Therefore, dissolved iron content of the order of 100 ppm, expressed as ferric oxide, do not necessarily indicate the ineffectiveness of any particular inhibitor. It is possible, also, to lose precipitated iron at other points in the system, so that this iron will not show up as dissolved iron in well-head water samples. For these reasons, we have placed much more reliance in the use of the well-head test coupons than we have in the iron content of the well-head water samples.

Supervision of inhibition procedures in the field is a real problem. Proper operation of the injection apparatus must be maintained, and the apparatus must be kept absolutely free from leaks. Well-head water samples may be taken periodically and analyzed in the plant laboratory for dissolved iron, and for the presence of the injected chemical if this chemical is water-soluble, and these analyses may be used as a check on proper injection of the treatment in the field. However, when oil-soluble inhibitors are used, analytical procedures for determination of the concentrations of the inhibitor in the well-head hydrocarbon liquid-phase samples become very complex or impossible. We are using well-head test coupons as the primary laboratory control of the field treatment operations, and find this procedure is very helpful in this connection.

In conclusion, the field testing of inhibitors and of chemical treatments to be used for reduction of distillate well corrosion has been handled on a more or less hit-or-miss basis in the past. The well-head coupon testing technique, accompanied by improvements in methods

of injection of the treatment, and also accompanied by tubing caliper surveys on a long-term basis, should give an increasing amount of reliable information on the field testing of inhibitors and chemical treatments in the future. This information should definitely point toward several inhibitors that should have wide application in reduction of distillate well corrosion. The wide and frank interchange of information, that has been so materially assisted by the N.G.A.A. Corrosion Research Project Committee, has been of great benefit to the operations of the Lone Star Producing Company, and we hope that this interchange will continue in the future and will result in an effective solution of this very serious problem.

Discussion

By C. K. Eilerts

Bureau of Mines, Bartlesville, Oklahoma

I would like to emphasize one of the subjects discussed by Mr. Bacon, and that is the need for the development of pumps used in treating gas wells subject to corrosion. There are two types of pumps in use at present; those driven by gasoline engines and the type equipped with a diaphragm motor and driven by expanding natural gas. The engine driven pumps have the advantage that the heat from the engine can be used to warm the pump and the solution in the storage tank, and thus prevent or minimize freezing difficulties in cold weather. Most of the engine driven pumps now manufactured are not designed for the service required, however, and are unnecessarily large and expensive. A pump with a capacity of 50 to 200 gallons per day against pressures up to 5,000 pounds per square inch is needed.

The gas required for pumps with diaphragm motors usually must be taken from the high-pressure flow stream of the well being treated. During cold weather the water and liquid hydrocarbons in the gas form solids (hydrates) in the lines and prevent the regulation of the gas supply. Mechanisms that operate satisfactorily during the summer months become nearly useless when atmospheric temperatures are 40° F. and lower. Traps for removing liquids from the supply line and throttling valves and regulators designed for cold weather operation are needed. A heater of some type that will prevent freezing of aqueous solutions in the supply tank, pump and flow lines, without creating a fire hazard, is almost a necessity if pumping operations are to be carried on continuously during the winter months.

Valve design for these low-capacity, high-pressure pumps is particularly important. The liquid entering the pump is usually under less than 50 pounds per square inch pressure, and the inlet valve must be relatively large in diameter so that it will admit liquid to the pump readily. If the diameter of the inlet valve is too large or if the seat is too soft, the valve will stick with only the low pressures on the supply tank to open

it. If the valve parts are too hard, the contacting surfaces will chip and cause the valve leakage that is so serious in these low-capacity pumps.

We are developing a cone-type check valve with interchangeable cones and seats. These valves have the desirable advantage that parts which become worn may be easily and quickly replaced with spare parts. The used cones and seats are then returned to Bartlesville and refinished in an accurate lathe for further use.

Contributions Invited

With the November, 1946, issue, it is planned to institute a news section in CORROSION.

Association members and other readers of the magazine are invited to send in news items for editorial consideration. These items should deal generally with the following subjects:

Activities of sections, research groups, and committees, new books, convention news, notes on unusual field conditions, phenomena, personals, and new products.

News arriving after deadline has been passed for a current issue will be held for publication in the next issue, providing the items still have news value or current interest.

Investigation and Control of Condensate Well Corrosion

By P. L. Menaul

Stanolind Oil and Gas Company, Tulsa, Oklahoma

THE DAMAGE shown by corrosion of the inner surfaces of tubing, chokes, and flow lines of condensate or gas distillate wells indicates the potential danger of failure of such equipment. It is obvious that the weakening and possible failure of well equipment and flow lines where such high pressures are encountered is very hazardous.

The Stanolind Research Laboratory has pursued the study and analyses of condensate waters from the Katy and South Jennings fields. All analyses showed a very high content of soluble iron. An examination showed that all the iron is in the ferrous condition as it is produced at the well head. The total dissolved solids is very low, 500 to 1,000 ppm., in waters from these distillate wells, indicating the condensation process involved in this type of well production.

It has been found by the writer that when condensate waters are exposed to air, the pH value of the solution is lowered. A fresh sample of condensate water of pH value 5.7 lowered to 4.8 on exposure to air, and the addition of one ml. of neutral hydrogen peroxide per 100 ml.

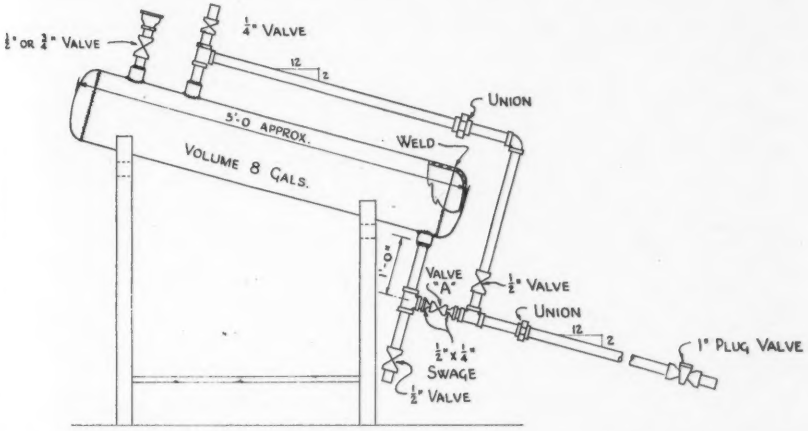


Figure 1—Gravity chemical feeder. All pipe is half inch, extra strong seamless, except for pressures in excess of 4,000 psi, where double extra strong seamless one inch is used. Valve "A" may be one-fourth inch needle valve, one-fourth inch plug valve, or one-half inch Kerotest forged steel gauge shut-off valve No. 110F. or 200D; all 4,000 lb. or 6,000 lb. test. Weld pipe in steel collar and weld collar to tank for all connections. Vessel is made to API-ASME Code for working pressure of well

caused a further drop to pH 3.1. This reaction was found to be characteristic of the ferrous salts of organic acids, such as ferrous acetate.

$$2\,Fe\,Ac_2 + HO{\cdot}OH \rightarrow 2\,Fe\,OH\,Ac_2$$

Ferrous acetate — Basic ferric acetate

Basic ferric acetate reacts with water to form the insoluble ferric hydroxide and free acetic acid.

$$FeOHAc_2 + 2\,H{\cdot}OH \rightarrow Fe(OH)_3 + 2HAc$$

Insoluble Ferric Hydroxide — Acetic Acid

The chemical extraction, isolation, and identification of mixed organic acids from condensate waters was described in 1944 (1).

These distillate wells produce a small volume of water. This water has left the producing formation in a vaporous form and has condensed at a zone of lower temperature and pressure. The most severe corrosion appears to be at this zone of condensation. Organic acids of the acetic acid series, which have existed in the sour swamp lands since their submergence, are produced from these formations under the temperature-pressure conditions of distillate well production.

Electrometric titration, in conjunction with other special tests of these organic acids extracted from condensate water, shows them to be of the acetic acid series. By converting the soluble ferrous salt to ferric, the electrometric titration of condensate water may be employed to estimate the organic acid content of

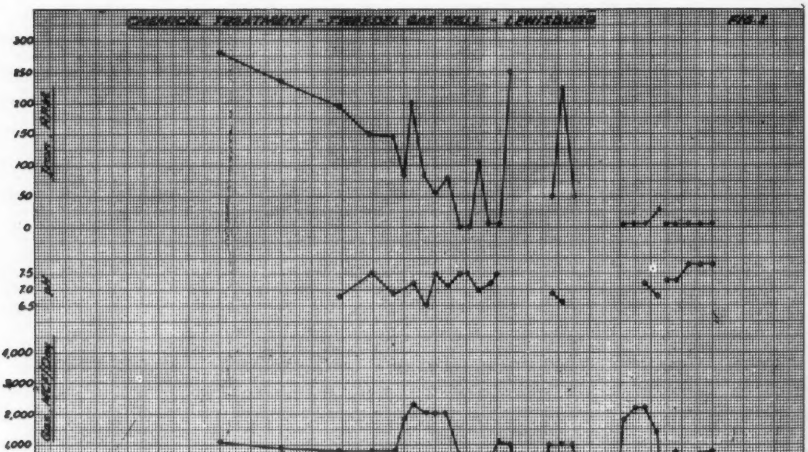


Figure 2.

the production (1), as follows:

Ferrous hydroxide is not completely precipitated at pH 7, but the ferric ion is completely precipitated and removed from solution at pH 5.5, which reaction liberates the anions as the free acid. This gives us a method of determining the total organic acid content by electrometric titration with standard alkali. This procedure is as follows: To a 100 ml. sample of condensate water, add ½ ml. neutral hydrogen peroxide (pH 7) and stir a few moments. This converts the ferrous salts to the ferric state and expels the dissolved carbon dioxide. The solution is then titrated with tenth normal sodium hydroxide, using a glass electrode pH meter, as described in the previous paper (1). The curve of the amount of standard sodium hydroxide used and pH value of the solution is a measure of the total organic acid content of the water.

The reaction of sodium acetate is very close to pH 7, so the organic acid content, calculated in parts per million as acetic acid, is taken as the number of ml. of tenth normal sodium hydroxide required to bring 100 ml. of the sample to pH 7, times the normality factor of acetic acid which is 60.

Since in these condensate wells, the production is in vaporous form at bottom-hole conditions, and condensation of water takes place where the pressure and temperature are lower, which is usually several thousand feet from the bottom of the

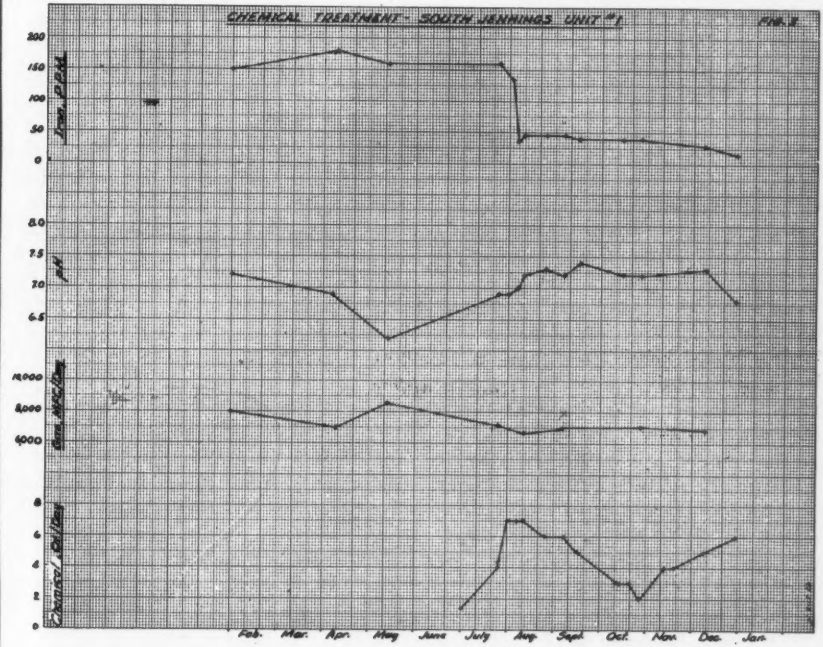


Figure 3.

well, a volatile, reacting agent will function. The acidic condensation will then be neutralized by reaction with the volatile compound.

When a well is to be put on chemical treatment, a chemical analysis of the water produced is made first so that the chemical to be injected can be chosen which will have no deleterious effects, as forming scale.

The chemical is injected into the casing annulus, when production is through the tubing. A gravity chemical feeder (see Figure 1) is used, having the casing pressure balanced. The feed into the casing is by gravity, and a ¼-inch needle valve is used to control the rate of flow.

Including a sight gauge and sight feed on the gravity chemical feeder would improve the control of chemical injection, but such instruments might involve a hazard at these high casing pressures.

The Stanolind Oil and Gas Company made a field trial of the chemical treatment to prevent corrosion in condensate wells in a Gulf Coast field. Numerous mechanical difficulties were encountered at first in injecting the chemical into the well. However, by the end of 1945, chemical was being injected into six wells and injection has been started in the seventh well.

Mechanical lubricators were used first to inject the chemical, but the brass fittings and packing in these injectors continued to give trouble, so the use of a specially designed gravity type of injector was started (see Figure 1). The results obtained in this well by the injection of chemicals are shown in Figure 2. It will be noted that the iron content of the produced water decreased from about 280 ppm to less than 3 ppm, at which the low iron content has been maintained to date. Approximately four quarts of chemical were injected per day. This amount is obviously an excessive treatment, although harmless, and in the future smaller dosages will be given. Satisfactory results of the treatment are indicated by the low iron content of the water produced.

In two other wells in the Lewisburg field, similar good results were obtained by the injection of chemical. In one of these wells, the iron content of the produced water has been decreased to less than 10 ppm for more than four months. Indications are that corrosion has been stopped in this well. In the second Lewisburg well, the iron content has also dropped to less than 10 ppm, and it is believed that the chemical treatment has become effective.

A condensate well in the South Jennings field, Unit No. 1, has also responded to chemical treatment. See Figure 3. Attempts to use a chemical pump were unsuccessful due to failure of the pump to inject fluid against the high pressure of the casing. On installation and use of the gravity type injector, the chemical treatment showed satisfactory reduction of the soluble iron content and neutralization of the water produced.

To summarize the results of field trials, it appears that chemical treatment has eliminated effectively corrosion in the four wells using the gravity injector. It is planned to continue the chemical treatment.

References

1. Menaul, Paul L., Oil and Gas Journal, Vol. 43, No. 27, Nov. 11, 1944, pp. 80-81.

Magnesium Anodes for the Cathodic Protection Of Underground Structures

By H. A. Robinson

The Dow Chemical Company, Midland, Michigan

MAGNESIUM METAL has several electrochemical properties which suggest its use as a galvanic anode for cathodic protection purposes. The most noteworthy of these are:

(1) A strongly anodic solution potential which places magnesium well above the common structural metals in the electromotive force series of elements. Its potential to ordinary steel ranges from —0.7 to —1.3 volts, depending largely upon the environment and the previous corrosion history of the steel. The voltages developed between magnesium and other commonly used metals (e.g., lead, copper) are equally high or higher.

(2) A theoretically small consumption of metal per ampere-hour of current supplied, i.e., a small electrochemical equivalent. The theoretical ampere-year equivalent of magnesium is about 8.8 pounds, or 1000 ampere-hours for every pound of magnesium used. The corresponding ampere-year equivalents for zinc and aluminum are 23.5 and 6.5 pounds, respectively.

Research Program

In view of the mentioned properties and the generally recognized advantages (1) of the galvanic anode for many installations of cathodic protection, a program of experimental field work was begun to determine how magnesium would perform as a sacrificial anode, and to evaluate what advantages it might offer for the practice of cathodic protection. The initial scope of this investigation was essentially limited to considerations of anode efficiency (the ratio of actual current output to theoretical current output per pound of metal consumed), and the effectiveness of magnesium anodes as a means of applying cathodic protection to underground structures such as pipelines. As the work progressed, and the answers to these questions became more obvious, it also became evident that there were numerous other requirements, which the galvanic anode of magnesium or any other metal must satisfy in order to reach maximum effectiveness as a practical method for applying cathodic protection. These have to do chiefly with:

(1) The corrosion pattern at the anode and the probability of segregation losses. The galvanic anode may operate very efficiently, but unless the corrosion is distributed uniformly, segregation losses may be so large as to make operating efficiency a matter of minor concern.

(2) The polarization characteristics of the anode as related to time, anode environment, and rate of anode consumption, i.e., current density. It is generally recognized that most anode metals are sensitive in terms of polarization to the presence of certain specific anions in their en-

vironment. The anions involved are usually those which react with the metal ions produced at the anode to precipitate and deposit a more or less insoluble and impervious film of corrosion product on the surface of the anode. Depending upon such factors as anode current density and the concentration of the polarizing anion, the resulting polarization may become evident in minutes, hours, days, months, or years. A limited amount of anodic polarization is tolerable insofar as it is offset by the polarization occurring at the cathode; nevertheless, it requires attention in that many galvanic anode installations are expected to operate for periods of 5-10 years or more.

Attempts to control either or both of the above anode performance variables have led to the use of controlled anode environments, or "chemical backfills," which are free from offending anions and generally make for better anode performance. For zinc anodes, this practice was first reported by O. C. Mudd (2) who describes the use of gypsum around the anode. Modifications of the gypsum backfill for zinc anodes have subsequently been described by H. W. Wahlquist (1).

The recognition of the performance variables described above, together with the need for backfills, have resulted in a program of progressively increasing scope, hence anode performance is now being correlated with such factors as:

(1) Anode composition and the concentration of cathodic impurities in the anode metal.

(2) Electrolyte composition and the concentration of polarizing anions.

(3) Current density and time.

(4) Backfill composition and the effect of time and weather on backfill stability and effectiveness.

(5) Soil resistivity, rainfall, and temperature.

(6) Anode design, i.e., effect of shape, size, core material, and core exposure.

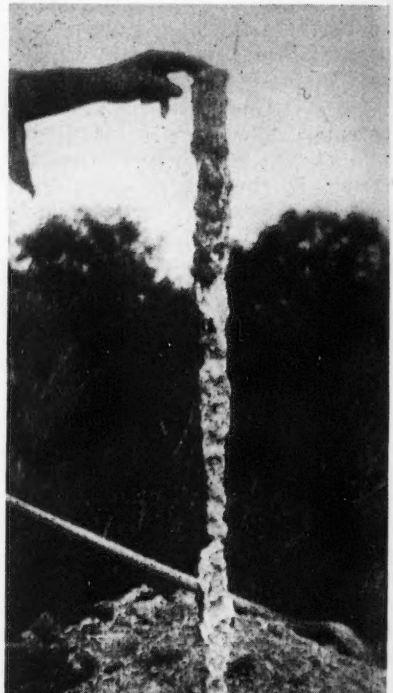


Figure 1—Typical corrosion attack leading to segregation.

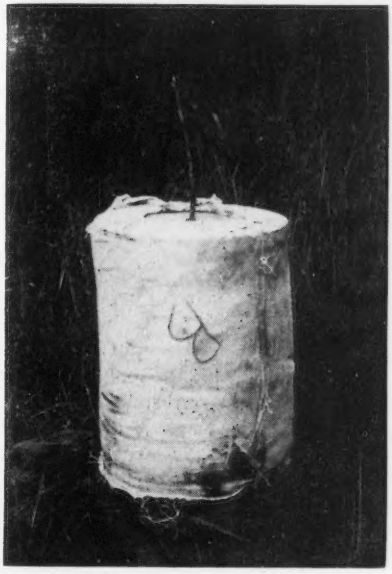


Figure 2—Typical anode unit ready for installation.

The above considerations relate primarily to the anode and the anodic reaction. In order to apply magnesium intelligently and effectively and to evaluate properly its advantages, the cathodic reaction must also be studied with a view to determining the best methods of application for such diverse structures as pipelines, storage tanks, lead-sheath cables, chemical process equipment, hot water heaters, and the like.

For many applications of cathodic protection with galvanic anodes, installation costs usually equal, and may often exceed, anode metal costs by a factor of two to three or more, in which case anode efficiencies and current costs become relatively less important. To such installations the magnesium anode, with its higher potential and greater throwing power, brings the promise of adequate protection with fewer anodes and a corresponding reduction in installation cost. Establishing this and other potential advantages of the magnesium anode has necessitated an increasingly extensive study of application variables such as:

(1) Current requirements and polarization at the cathode.

(2) Effect of the environment on cathodic polarization and the formation of cathodic films.

(3) Current distribution, anode distribution, and the effect of soil resistivity on current flow and distribution requirements.

Such is the present and future scope of the investigation, of which, obviously, only a part can be reported here.

Early Field Work

Experimental field work was begun some six years ago using pure commercial (electrolytic) magnesium, commonly known as "cell" magnesium, for the anode. This material is nearly pure magnesium having a relatively large and variable (0.010-0.050%) iron content, together with a somewhat less variable amount of manganese and other less significant impurities. A typical analysis of this metal is given below:

Element	Percent
Magnesium	99.878 (by difference)
Iron	0.030
Manganese	0.080
Copper	0.003
Nickel	0.001
Aluminum	0.003
Silicon	0.005

The anodes used were extruded rods, 1.3-inch in diameter and some four to six feet long. These were

installed in various ways: (a), by simply driving the anode into the earth wherever soil conditions permitted; (b), by drilling with an auger a slightly undersized hole, filling this with mud and forcing in the anode; and (c), by boring an oversized hole, inserting the anode and backfilling with slaked lime. Lime was used as a backfill largely because it was thought that local action on the magnesium would be caused primarily by acid soil conditions.

Several installations of this kind were made in the vicinity of Midland, Michigan, with variable results depending largely upon local soil conditions. The soil in this locality is typical glacial drift consisting of 1000-3000 ohms/cc clay having an overburden of high resistivity sand, ranging from several inches to 25 feet in thickness. In general, the above installations provided adequate current where soil resistivity was low (3000 ohms/cc or less) but anode performance was variable and seldom satisfactory as regards efficiency and distribution of corrosion attack.

Several such trial installations were made in 1941 throughout the central and southwestern states by a number of major pipeline companies using pure magnesium stick. The performance of one of these installations has been reported by G. R. Olson (3). In general, the results described by Olson are typical of those which were observed on the other installations made with cell magnesium rod, in that:

(a) Current flows were adequate to establish satisfactory pipe-to-soil potentials, except where high resistance soils were encountered.

(b) Anode life was excessively short due to the combined effects of segregation and a high rate of local corrosion. The long, small-diameter rods were especially susceptible to segregation in that they were likely to traverse several soil strata of widely differing corrosiveness and resistivity. Typical corrosion attack leading to segregation is illustrated in Figure 1.

In view of these results, a shorter

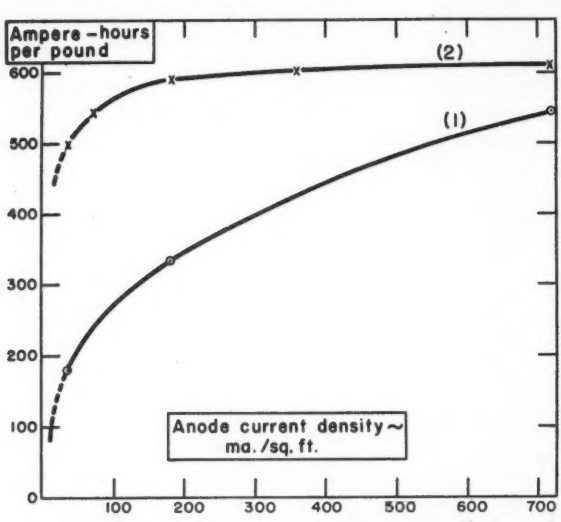


Fig. 3 - Effect of current density on current efficiency of magnesium anodes. Relative performance of (1) pure commercial (cell) magnesium and (2) Dowmetal (Mg-6%Al-3%Zn) alloy anodes operating in saturated $CaSO_4$ solution.

and more massive anode, which could be concentrated substantially in a single soil stratum, was made. This anode, measuring four inches in diameter by six inches long, was cast around a core of ⅛-inch stranded steel cable, the entire assembly weighing about 4.75 pounds. Such anodes were encased in canvas bags containing chemicals, such as lime, borax, and gypsum, intended to reduce the rate of local corrosion.

A typical anode unit ready for installation is shown in Figure 2. This type of anode gave a slight improvement in service life, but at best, the consumption of metal exceeded the theoretical by a factor of three or more.

Further field work was terminated by the outbreak of World War II at which time magnesium metal became unavailable for experimental work.

Laboratory Investigations

The erratic behavior, short life, and poor efficiencies observed in the early field tests using cell magnesium led to an extensive laboratory investigation of the factors affecting magnesium anode performance. The immediate objective of the early laboratory work was to find a chemical environment in which cell magnesium would operate efficiently and corrode uniformly. Tests were run on a large number of different aqueous electrolytes without finding a chemical composition which was entirely suitable. In several of the electrolytes tested, notably sodium dichromate, sodium chromate, sodium thiocyanate, and sodium salicylate, better than average performance was noted; but satisfactory anode efficiencies could not be obtained without incurring an excessive amount of polarization, i.e., drop in anode potential. Furthermore, the chemicals which made for some improvement in anode performance were highly soluble salts susceptible to rapid leaching when used in the field.

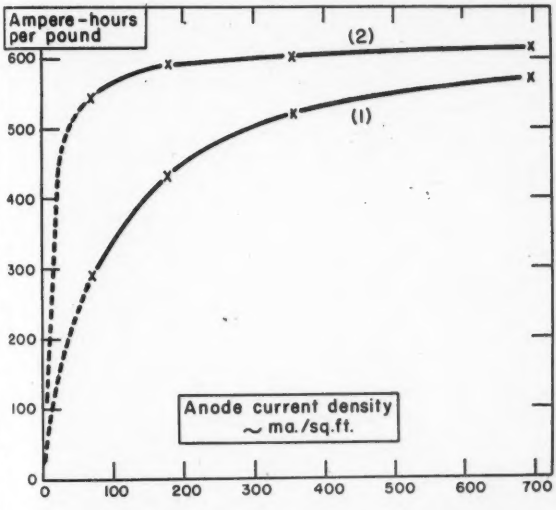


Fig. 4 - Effect of electrolyte on anode performance. Dowmetal (Mg - 6% Al - 3% Zn) alloy anode operating in:
(1) Saturated NaCl solution
(2) Saturated $CaSO_4$ solution

In seeking to explain the poor efficiencies obtained with cell magnesium anodes, a study was made of the effect of current density on

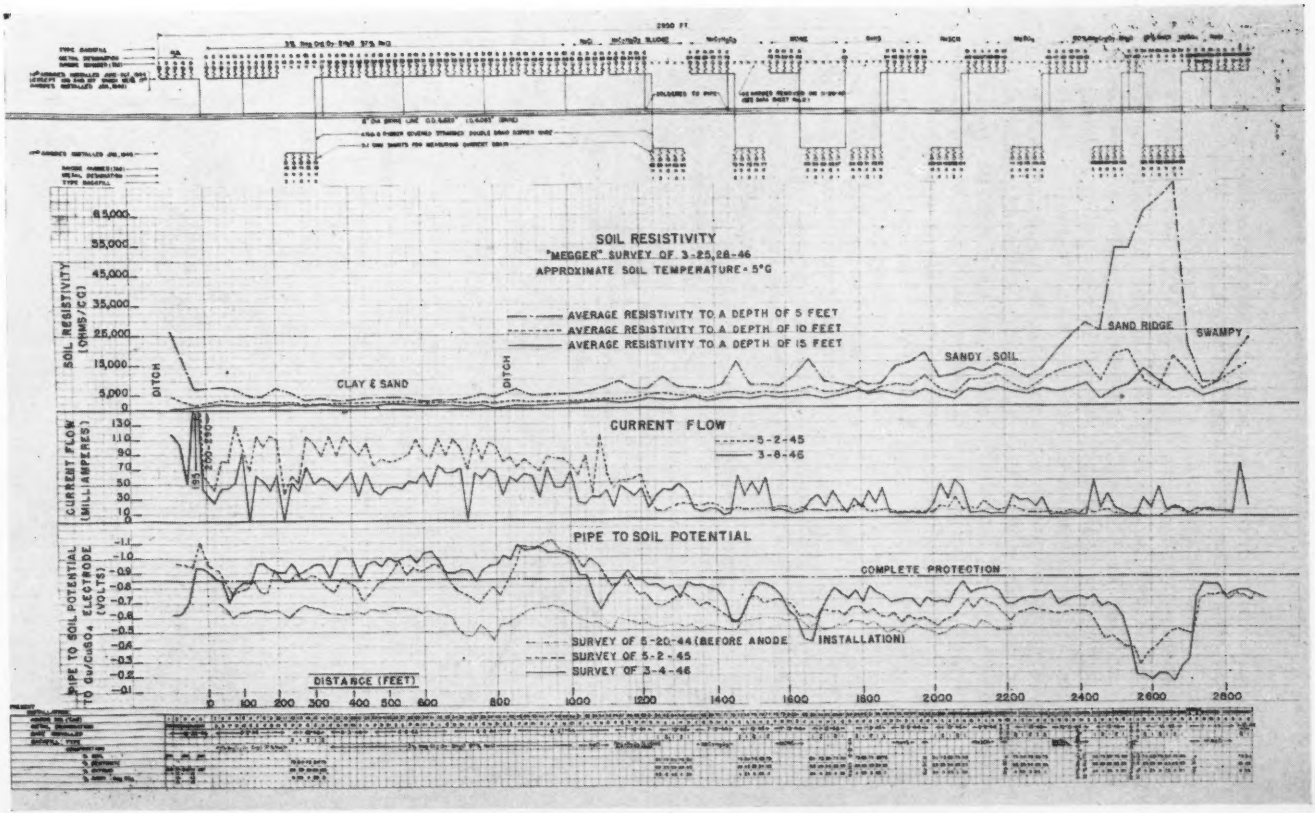


Figure 5—Experimental magnesium anode installation on 6-inch dia. brine line.
o—present anode installation —a moved on 11-26-45.

the rate of local corrosion. This was done by measuring the rate of hydrogen evolution from the anode for both open and closed circuit conditions. It was found that the rate of local corrosion increased with rise in current flow and that the rate of increase in local corrosion approached the rate of increase in useful corrosion. These data, together with the observation of a high rate of open circuit corrosion, served to explain why low efficiencies were observed with cell magnesium.

The hydrogen evolution technique for investigating the local corrosion-current density relationship was then applied to the magnesium base alloys containing aluminum, or aluminum and zinc, and later was used to determine the effect of various electrolytes on the rate of local corrosion. For the high purity Mg-Al* and Mg-Al-Zn alloys, the rate of local corrosion also was observed to rise with increase in current density; but the rate of rise was substantially less than the rate of increase in useful corrosion. It was obvious from these data that anode efficiency was dependent upon current density, and that the high purity Mg-Al and Mg-Al-Zn alloys would perform more efficiently than cell magnesium. This was confirmed by running laboratory tests in which anodes were operated at various current densities, and efficiencies were calculated from weight losses. Typical laboratory performance curves for cell magnesium and high purity Mg-6%Al-3%Zn alloy are shown in Figure 3.

Attention was then turned to the effect of various electrolytes upon the rate of local corrosion and its relation to current density. The most outstanding observation was that: (1), the rate of local corrosion, and (2), the rate of increase in local corrosion with increasing current density, were considerably greater in chloride than in sulfate electrolytes. The corresponding effect on anode efficiency is illustrated in Figure 4.

The factors affecting the uniformity of anode consumption and the probability of segregation were also studied in the laboratory. The three major variables which influence the

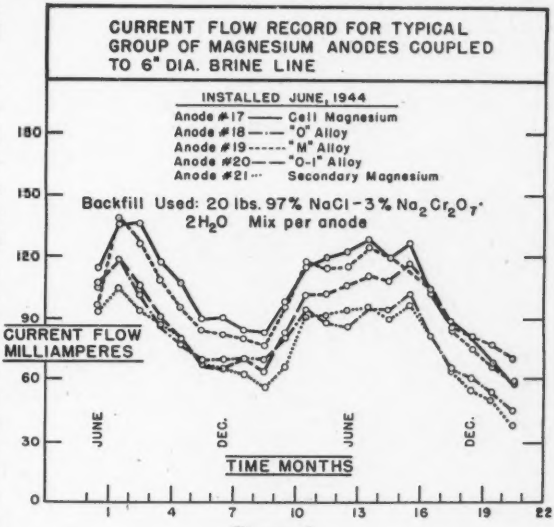


Figure 6.

Figure 5—Experimental magnesium anode in ...tation on 6-inch dia. brine line. o—present anode installatio ...moved on 11-26-45.

*EDITOR'S NOTE: Throughout this paper, the chemical symbols for magnesium, aluminum, and zinc will be used when referring to the alloys.

corrosion pattern at the anode were found to be:

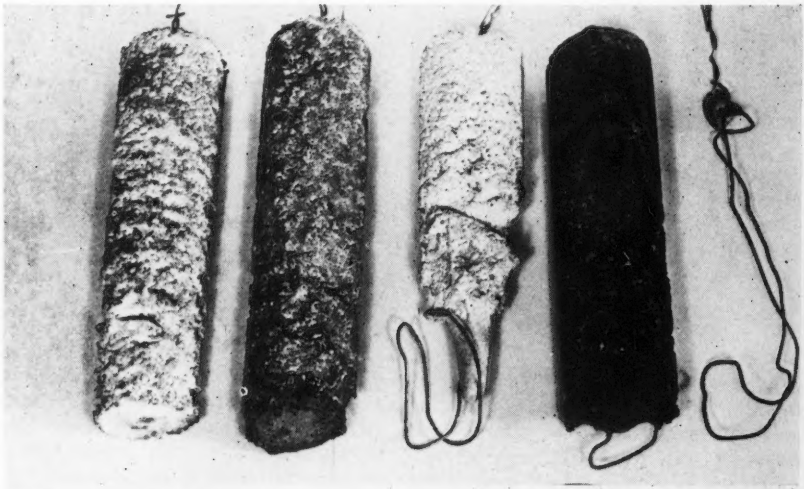
(1) Anode current density.

(2) Kind and concentration of electrolyte.

(3) Composition of the anode metal.

The effect of current density on the corrosion pattern at the anode is pronounced and common to all of the magnesium compositions tested. At very low current densities (below about 35 ma./sq. ft.), the corrosion attack is characterized either by pitting or poor distribution. As the current density is increased the distribution of attack improves, until at high current densities (200 to 400 ma./sq. ft.) uniform consumption of anode metal is observed with practically all of the anode compositions investigated.

The current density at which uniform distribution of corrosion is obtained depends both upon anode composition and upon the composition and concentration of the electrolyte used. In electrolytes containing high concentrations (5 percent to saturation) of soluble salts, such as sodium chloride, potassium chloride, calcium chloride, and sodium sulfate, high current densities must be employed to achieve uniform anode consumption. However, in electrolytes of limited solubility, e.g., calcium sulfate and magnesium sul-



ANODE	12	13	14	15	16
METAL DESIG.	C	O	M	01	S
BACKFILL COMP.		97% NaCl	3% $Na_2Cr_2O_7 \cdot 2H_2O$		
STRUCTURE PROT.		6" Dia.	Brine Line		
DAYS INSTALLED	539	539	539	539	539
AVE. AMPERES	.0702	.064	.1151	.1050	.0895
AMPERE HOURS	907.0	828.0	1488.0	1358.0	1157.0
WT. LOSS IN LBS.	3.562	2.845	6.25	3.105	12.72
% EFFICIENCY	25.45	29.1	23.8	43.7	9.1

Figure 7.

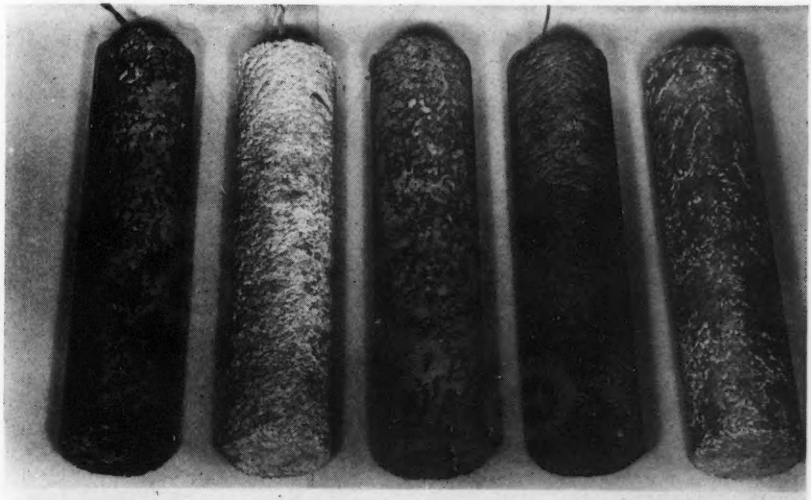
fite, good distribution of corrosion attack has been observed on laboratory anodes at current densities as low as 35 to 70 ma./sq. ft. The nature of this effect is not clearly understood. It may be related either to the concentration of electrolyte or to the specific combination of ions employed.

In the electrolytes favorable to distributed attack, e.g., saturated calcium sulfate solution, the minimum current density, at which uniform consumption of anode metal commences, is determined by the composition of the anode. Thus, for cell magnesium and the Mg-6%Al-3%Zn alloy, a well distributed attack is observed at current densities as low as 35-70 ma./sq. ft., whereas, for high purity magnesium, and the magnesium-aluminum alloys, current densities of from 200-400 ma./sq. ft. are required if uniform anode consumption is to be realized.

The general conclusions derived from the laboratory investigation are essentially as follows:

(1) The cell magnesium anode is not likely to perform efficiently except when operating at high current densities.

(2) High purity Mg-Al and Mg-Al-Zn alloys perform more efficiently than cell magnesium over the low



ANODE NO.	83	84	85	86	87
METAL DESIG.	O	M	01	S	C
BACKFILL COMP.		None			
STRUCTURE PROT.		6" Dia.	Brine Line		
DAYS INSTALLED	494	494	494	475	475
AVE. AMPERES	.0107	.0132	.0107	.0110	.0111
AMPERE HOURS	127.3	156.8	127.2	127.2	128.3
WT. LOSS IN LBS.	.329	.8315	.322	.3683	.302
% EFFICIENCY	38.7	18.85	39.5	34.55	42.5

Figure 8.

current density range normally obtaining for field installations.

(3) Of the alloys tested to date, the high purity Mg-6%Al-3%Zn composition has the best over-all anode performance characteristics.

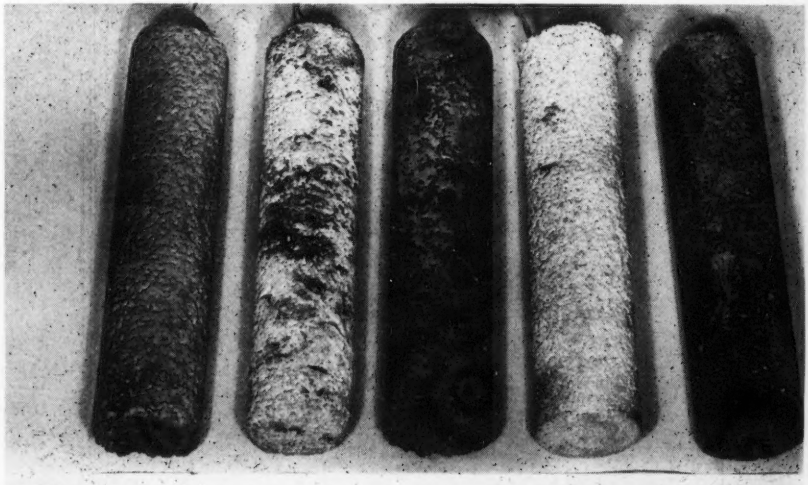
(4) Magnesium anodes operate more efficiently in sulfate than in chloride electrolytes.

(5) The optimum distribution of corrosion attack at the anode is obtained with saturated solutions of either calcium sulfate or magnesium sulfite as the electrolyte.

The Testing of Field Anodes and Backfills

Potentially significant differences exist between the test conditions employed in the laboratory and the operating conditions likely to be encountered in the field. For the small scale laboratory investigation, the anodes employed were machined from small castings, and the tests were run in homogeneous, aqueous electrolytes, which were fluid and usually contained not less than about 70 percent by weight of water. The duration of the laboratory tests ranged from two to 10 weeks, hence long-time polarization effects would not necessarily be observed.

In the field the anodes used are large castings and these are installed in the "as cast" condition. The electrolyte may or may not be homogeneous depending upon backfill



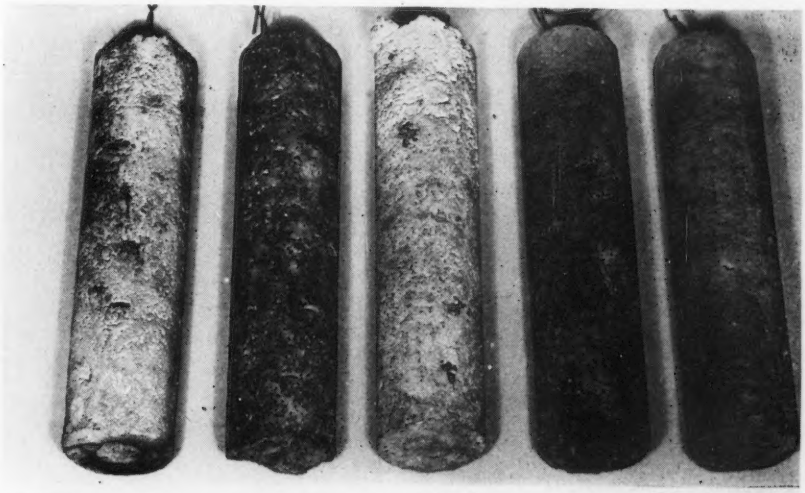
ANODE	111	112	113	114	115
METAL DESIG.	S	C	O	M	01
BACKFILL COMP.		$MgSO_4$			
STRUCTURE PROT.		6" Dia.	Brine Line		
DAYS INSTALLED	409	409	409	409	409
AVE. AMPERES	.01405	.01124	.0084	.00986	.00916
AMPERE HOURS	138.0	110.4	82.5	96.8	90.0
WT. LOSS IN LBS.	.611	.571	.331	.673	.317
% EFFICIENCY	22.6	19.3	24.9	14.4	28.3

Figure 9.

practice, and the fluidity and water content of the field electrolyte may vary over a wide range, depending upon the installation site and the depth at which the anode is installed. Furthermore, field installations are expected to operate for periods of five to 10 years or more.

Because of these and other differences between field and laboratory conditions, a program of field research paralleling the laboratory program has been undertaken. The field testing of anodes and chemical backfills is being carried out both at Midland, Michigan, and by The Dow Chemical Company's Texas Division at Freeport, Texas. A part of this program has already been described by Hart and Titterington (4).

One of the early experimental installations made on bare pipe in the Midland area is shown in Figure 5. This installation was begun in June of 1944 and originally comprised some 137 anodes of five different magnesium compositions, installed in eight different chemical backfills. The anodes used were cylindrical castings, four inches in diameter by 16 inches long and weighing 13-14 pounds. A spiral of galvanized iron wire, which served both as a core and as a means for making connections, was cast into each anode.



ANODE NO.	122	123	124	125	126
METAL DESIG.	C	O	M	OI	S
BACKFILL COMP.		90% $Na_2Cr_2O_7 \cdot 2H_2O$ 10% NaCl			
STRUCTURE PROT.		6" Dia. Brine Line			
DAYS INSTALLED	405	405	405	405	405
AVE. AMPERES	.01012	.00963	.0110	.00822	.00719
AMPERE HOURS	98.4	93.6	107.0	79.9	69.85
WT. LOSS IN LBS.	.441	.322	.448	.2404	.269
% EFFICIENCY	22.3	29.1	23.9	33.2	26.0

Figure 10.

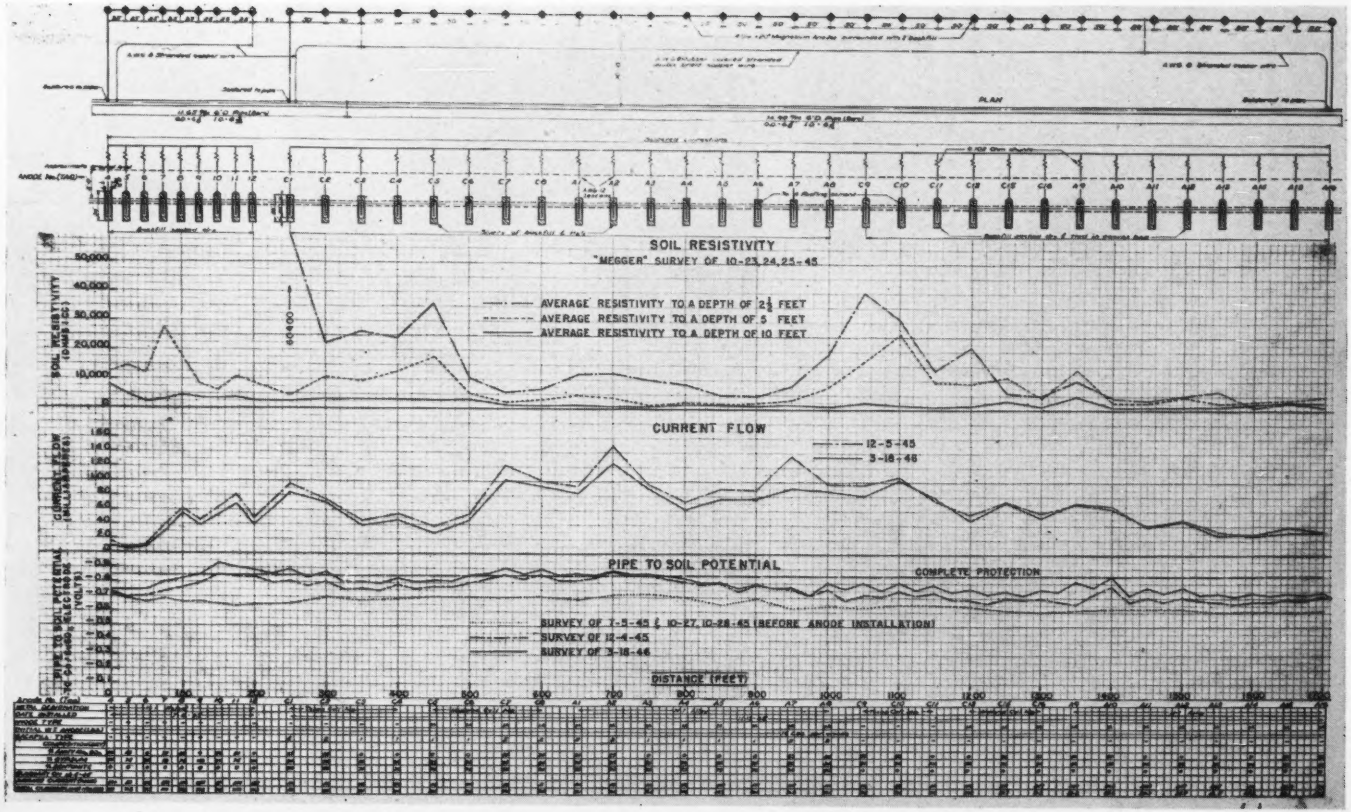


Figure 11—One of the more recent experimental installations, made during November, 1945. Magnesium anode installation on 6-inch dia. gas main.

The anode compositions used were nominally the following:

Designation	Composition Percent
C	Mg-0.07 Mn-0.030 Fe
M	Mg-1.5 Mn-0.004 Fe
S	Mg-6 Al-3 Zn-0.2 Mn-0.001 Fe
O	Mg-8 Al-0.5 Zn-0.2 Mn-0.015 Fe
O-1	Mg-8 Al-0.5 Zn-0.2 Mn-0.001 Fe

Because of war-time restrictions, however, it was necessary to use scrap metal in making the above alloys, and the actual analysis of the anodes failed, for the most part, to meet the nominal specifications with regard to either major or minor constituents. Composition "C" (pure Mg) was heavily contaminated with aluminum and zinc, composition "M" with nickel, and composition "S" analyzed very low in zinc and was also heavily contaminated with nickel. Only the "O-1" alloy approached the nominal specification except for an occasional iron contamination.

The backfills used included the following:

Designation	Composition
(1)	97 percent sodium chloride —3 percent sodium dichromate
(2)	None—(original earth)
(3)	Sodium salicylate
(4)	Sodium salicylate sludge
(5)	Sodium acid sulfide
(6)	Sodium thiocyanate
(7)	Magnesium sulfate
(8)	90 percent sodium dichromate—10 percent sodium chloride

The anodes were installed in earth-auger bored holes some 3-4 feet deep on 20-foot centers along some 3,000 feet of bare 6-inch pipe whose depth ranged from 18 to 24 inches. No attempt was made to locate the anodes in soil strata of low resistivity, inasmuch as the soil resistivity survey shown in Figure 5 was not then available. The backfills were applied simply by mixing the chemicals with the excavated earth as it was returned to the hole after placing the anode.

The more general data on the performance of the installation, i.e., soil resistivities, current flows, and pipe-to-soil potentials, are given in Figure 5. For the most part the following observations apply:

(1) Pipe-to-soil potentials in excess of —0.85 volts to a

Figure 11—One of the more recent experimental installations, made during November, 1945. Magnesium anode installation on 6-inch dia. gas main.

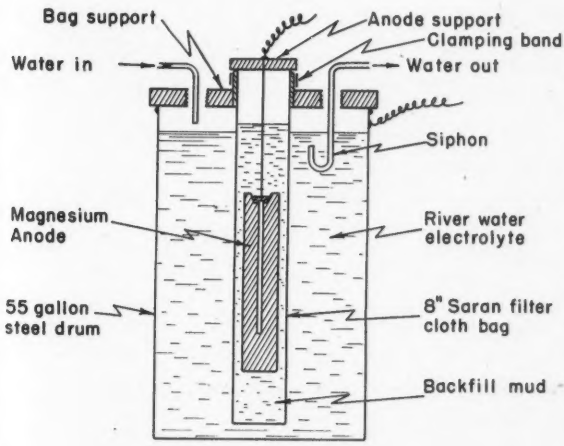


Fig. 12—Experimental cell used for testing 4" x 20" magnesium field anodes in the laboratory

copper/copper sulfate electrode are obtained wherever the average resistivity of the top soil (upper 5 feet) drops below about 5,000 ohms/cc. Potentials 0.1 and 0.2 volts higher than the original pipe-to-soil potential are observed for soil resistivities of 5000-10,000 ohms/cc. Sharp drops in pipe-to-soil potentials are noted for soil resistivities exceeding 10,000-15,000 ohms/cc, indicating failure of current to reach the pipe in such areas even though the paralleling, but deeper, anode installation is supplying some current. Inspection of pipe in the high resistivity zones shows no pitting but instead a thin, uniform coating of rust.

(2) Although current flows have decreased somewhat, the pipe-to-soil potentials obtaining on 3/2/46 are generally higher than those measured on 5/2/45, indicating continued polarization of the pipe.

The current flows to the individual anodes of this installation have been measured weekly, and the plotted values for a typical group of anodes are shown in Figure 6. The most outstanding feature of the current flow record is a distinct seasonal fluctuation in current flow, the maximum flow being observed in late summer and the minimum in mid-winter. Minor fluctuations probably associated with rainfall and soil moisture variations are also apparent. In addition to these effects, a persistent trend toward lower current values is observed. This is attributed largely to polarization at the pipe, inasmuch as new and deeper anode installations on well polarized sections of the pipe do not restore current flows to the original values, whereas, similar installations on the more poorly polarized sections show current flows in excess of those obtained with the original installation. The decline in current flow could also be due in part to the leaching away of the backfills, all of which were highly soluble salts.

On November 26, 1945, after 14-18 months of operation, some 45 anodes of the original installation were removed for inspection and the determination of weight losses. Removal of corrosion product was effected by wire brushing in a stream of water followed by immersion in 20 percent aqueous chromic acid containing about one percent silver nitrate, after which the anodes were rinsed, dried, and weighed. The results obtained are given in Table I.

The general appearance of the anodes after cleaning, together with additional data relating to the duration of the test period, average current flow, total ampere-hours recovered, and weight losses, are given in Figures 7, 8, 9, and 10.

In general, the best over-all performance was obtained with the "O-1" alloy, this being the composi-

TABLE I

Alloy Designation	Percent Current Efficiency Backfill Designation							
	No. 1	No. 2	No. 3	No. 4	No. 5	No. 6	No. 7	No. 8
"C"	25	42	19	24	2	12	19	22
"M"	24	19	21	16	4	7	14	24
"O"	29	39	32	15	40	42	25	29
"O-1"	44	40	33	38	44	30	28	33
"S"	9	35	26	13	37	19	23	26

tion which most closely approached specifications and was least contaminated with heavy metal impurities. The performance of the secondary metal (S) was adversely affected by low zinc and high nickel concentrations, and current failures have already been noted with several of these anodes. Contamination with nickel probably affected the performance of the "M" alloy also.

Some of the anodes operated at current flows so low (10-20 ma.) as to approach open circuit conditions. The corrosion rates observed on these ranged from as little as 0.216 pounds to as much as 0.626 pounds per year. For such corrosion rates, an anode life of from 20-60 years is indicated. For the anodes operating at the higher current flows, 60-115 ma., life expectations range from 1.5 to 7.5 years depending upon the efficiencies obtained.

Since the above installation was made, the composition and preparation of the backfill have been revised substantially as a result of new laboratory data and the field experiments carried out at Freeport, Texas (4). The backfills currently being used are semi-fluid, bentonite clay muds in which various chemicals such as gypsum (calcium sulfate), sodium sulfate, chromic acid, and magnesium oxide or hydroxide are dispersed in various proportions. Such backfills have a number of ac-

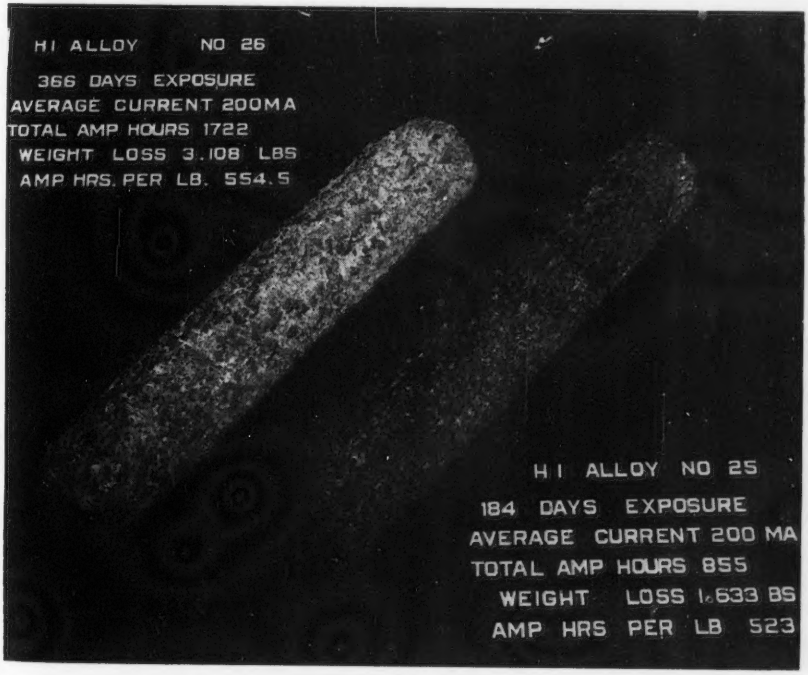


Figure 13.

tual and potential advantages in practice:

(1) The semi-fluid muds make intimate and voidless contact with both the anode and the adjacent earth.

(2) If prepared with reasonable care, the mud backfill supplies a homogeneous environment for the anode.

(3) Chemical stability should be very good in that bentonite clays exhibit a high degree of water impedance which should reduce leaching action to a minimum.

In addition to the mud backfills a number of bentonite-free chemical combinations are also being investigated. These include the following:

(1) 100 percent $CaSO_4 \cdot 2H_2O$ (gypsum)
(2) 50 percent $CaSO_4 \cdot 2H_2O$ · 50 percent $Mg(OH)_2$
(3) $CaSO_4 \cdot 2H_2O$ (gypsum) · Na_2SO_4 (sodium sulfate) mixtures (various proportions)
(4) 75 percent $Mg(OH)_2$ (magnesium hydroxide) · 25 percent Na_2SO_4 (sodium sulfate)
(5) $MgSO_3$ (magnesium sulfite) · $Mg(OH)_2$ (magnesium hydroxide) (various proportions)

Preliminary field testing of the mud backfills has been carried out in the vicinity of the sea water flume at Freeport, Texas. These tests, which were of six months duration,

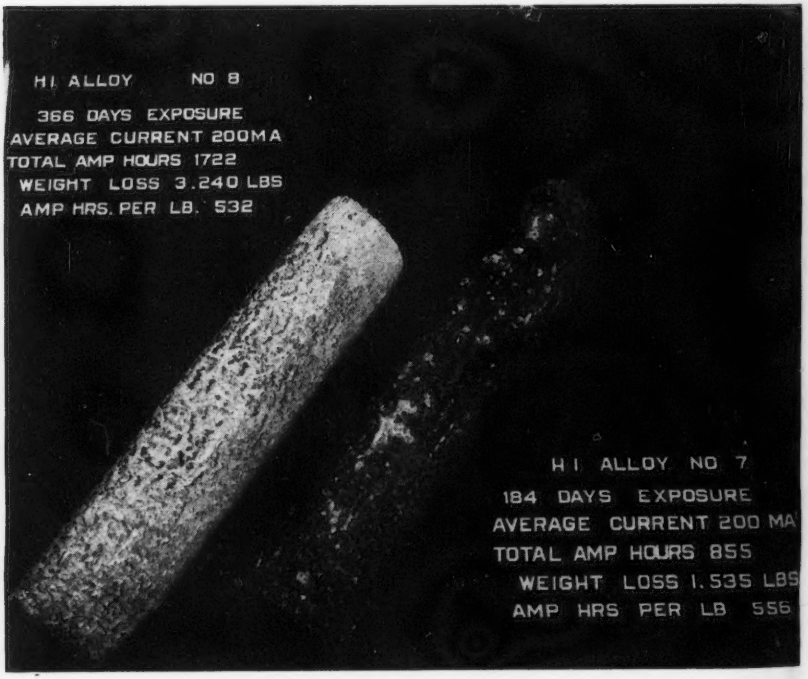


Figure 14.

were made with both cell magnesium and high purity Mg-6%Al-3%-Zn alloy anodes, operating at current densities ranging from 30 to 200 ma./sq. ft. Three anodes were tested for each of the four current densities employed.

The current efficiencies obtained with the anodes ranged from 30-35 percent at 30 ma./sq. ft. to 50-55 percent at 200 ma./sq. ft., the over-all average efficiency for all anodes tested being 45 percent.

The current efficiencies observed with cell magnesium ranged from 10 percent to about 35 percent, the over-all average efficiency for all the cell magnesium anodes tested being about 27 percent. No particular correlation of efficiency with current density could be observed with the cell magnesium anodes, whereas efficiencies tended to increase with current density in the case of the alloy anodes.

The Mg-6%Al-3%Zn anodes operated at maximum efficiency (average over-all efficiency 55 percent) in a bentonite-chromic acid backfill containing 99.5 percent bentonite and 0.5 percent chromium trioxide. For cell magnesium the best backfill was 100 percent $CaSO_4 \cdot 2H_2O$ (gypsum) in which an average over-all efficiency of 32.5 percent was realized.

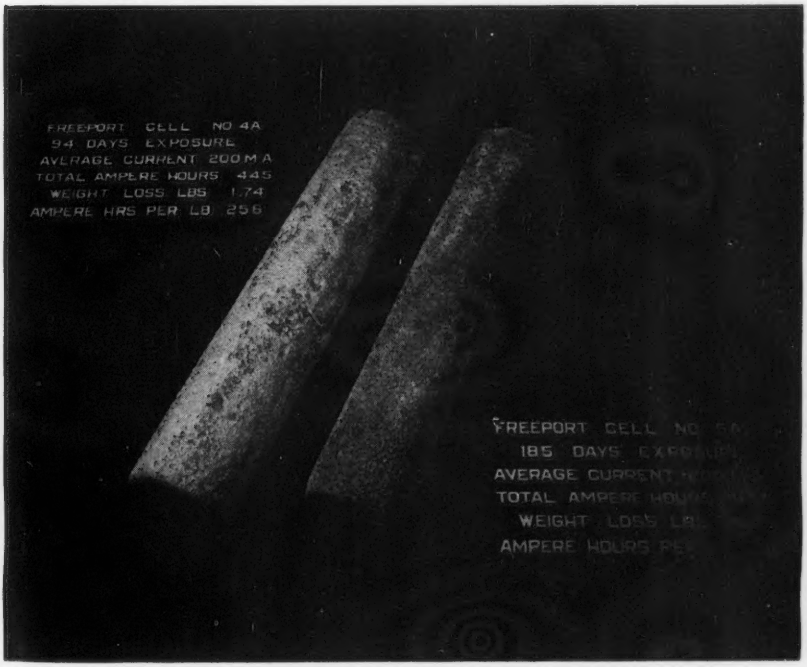

FREEPORT CELL NO 4A
94 DAYS EXPOSURE
AVERAGE CURRENT 200 M A
TOTAL AMPERE HOURS 445
WEIGHT LOSS LBS 1.74
AMPERE HRS PER LB 256

Figure 15.

The test data obtained at the flume site are believed to be conservative in view of the high salinity of the ground water in this area.

Field testing of similar backfill compositions is also being carried out in the vicinity of Midland, Michigan. One of the more recent experimental installations, made during November, 1945, is shown in Figure 11. This is a multi-purpose installation made to:

(1) Protect the gas line through a wet area in which the pipe traverses several outcrops of relatively low resistivity clay.

(2) Determine the relative performance of Mg-6%Al-3%Zn alloy and cell magnesium anodes.

(3) Compare the performance of the bentonite-mud backfills with ordinary chemical backfills of gypsum or gypsum and sodium sulfate.

(4) Test the feasibility of using backfills sacked around the anode before installation.

(5) Investigate the feasibility of using longer anode spacings on bare pipe.

The anodes used for this installation were castings, 4 inches in diameter by 20 inches long and weighing about 16 pounds. These have a core rod of ⅛-inch galvanized pipe, to which an insulated copper lead wire some 10 feet long is connected. The anodes were installed in 8-inch auger-drilled holes with the top of

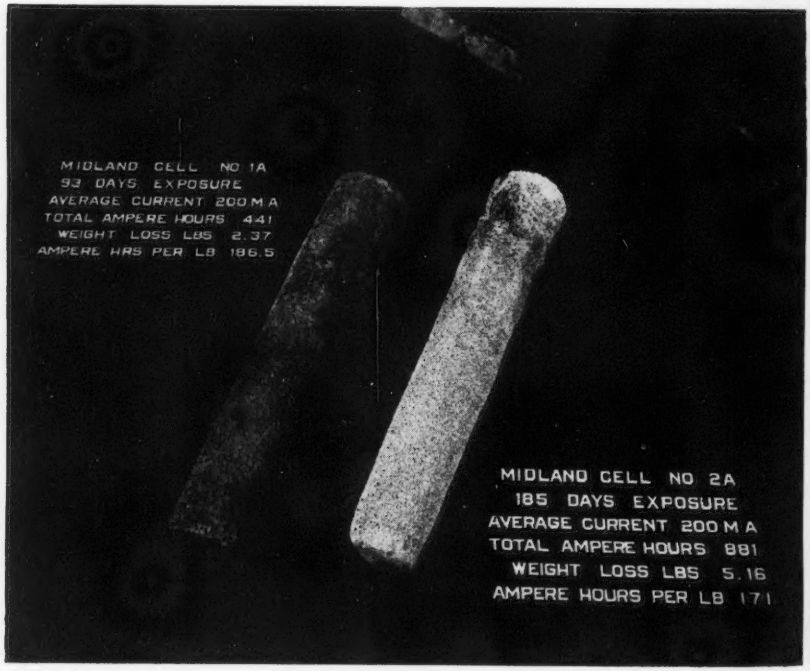

MIDLAND CELL NO 1A
93 DAYS EXPOSURE
AVERAGE CURRENT 200 M A
TOTAL AMPERE HOURS 441
WEIGHT LOSS LBS 2.37
AMPERE HRS PER LB 186.5
MIDLAND CELL NO 2A
185 DAYS EXPOSURE
AVERAGE CURRENT 200 M A
TOTAL AMPERE HOURS 881
WEIGHT LOSS LBS 5.16
AMPERE HOURS PER LB 171

Figure 16.

the anode at approximate pipeline level. Because of irregularities in the terrain, the depth of the anodes below grade ranged from as little as three feet to as much as 6.5 feet.

The data currently available on the performance of this installation are plotted in Figure 11. As is indicated by the resistivity survey, the soil consists of a low resistivity clay stratum (1000-3000 ohms/cc) overlaid by a layer of high resistance sand of variable thickness. The curve for current flow fails to parallel the 5-foot resistivity survey primarily because of the variations in anode depth mentioned above, i.e., some anodes were set deep enough to reach low resistivity clay in areas where the 5-foot resistivity was high.

Pipe-to-soil potentials, some three months after installation, are 0.1 to 0.2 volts more negative than the original pipe-to-soil potential all along the line. A pipe-to-soil potential of —0.85 volts has been established over about 500 feet of line, and there is evidence of continuing polarization at the pipe. On this installation, all pipe-to-soil potentials were measured at a point about one-half inch from the pipe in order to eliminate some of the IR drop, which is normally included in potential measurements made at grade level. Measurements made in this way show less protection (by some 30-50 mv.) than measurements made at grade level.

TABLE II

Anode Composition	% Current Efficiency Period of Operation, Months		
	3	6	12
Mg-6% Al-3% Zn Alloy	52.5	52.3	55.4
Mg-6% Al-3% Zn Alloy	52.1	55.6	53.2
Freeport cell magnesium	25.6	20.2	....
Midland cell magnesium	18.6	17.1	....

Measurements of pipe-to-soil potential, made both opposite the anodes and at the mid-points between anodes, indicate a satisfactory degree of current distribution from anodes installed on 50-foot centers and located 10 feet from the pipe. The potentials at the mid-points are some 30-50 mv. less than the potentials directly opposite the anodes.

Field anodes and backfills are also being investigated in the laboratory by means of large cells similar to those shown in Figure 12. These cells are modeled after the smaller cells used in earlier laboratory work. The design and construction are such that a field-size anode can be accommodated, and provision is made for operating the anode in the backfills used in the field. A 55-gallon steel drum serves as the cathode, and the annular space between drum and backfill is filled with river water, the latter electrolyte having been selected as being reasonably representative of ground water. In practice, a slow flow of river water is maintained through the drum to reduce cathodic polarization and to prevent an excessive build-up of alkali. The conditions obtaining in these cells are believed to be representative of those existing in the field, wherever the anode is located below the water table, as would often be the case in low, wet areas.

For comparing the performance of different anode compositions or backfills, such cells are connected in series and operated in groups of 20-30 or more. The current flow through the series is maintained at a constant, predetermined value for the du-

ration of the test run by means of automatic controllers. Anode potentials are measured periodically to detect polarization effects by means of suitable reference electrode inserted into the backfill alongside the anode.

Tests of this type have been under way in the laboratory since March of 1945. In these tests both Mg-6%Al-3%Zn alloy and cell magnesium anodes have been operated in bentonite mud [60 percent bentonite-20 percent gypsum - 20 percent Mg $(OH)_2$] backfills at a constant flow of 200 ma. (≅ approx. 100 ma./sq. ft.) for periods ranging from six months to one year. The current efficiencies obtained are given in Table II.

The appearance of the anodes removed from the above tests, together with additional data on ampere-hour recovery and weight losses, is given in Figures 13, 14, 15, and 16. As can be seen from these photographs, the corrosion attack on the alloy anodes is considerably rougher than that on the cell magnesium. This is thought to result from the presence of an aluminum-rich "chill skin" on the alloy anodes, a condition which did not exist on the machined anodes used in the laboratory. Indications are that corrosion becomes more uniform once the "chill skin" has been corroded away.

Conclusions

(1) For current densities in excess of about 40 ma./sq. ft., laboratory data indicate that electrical recoveries of 500-600 ampere - hours per pound, together with good distribution of corrosion attack and freedom from polarization effects, may be expected from Mg-6%Al-3%Zn anodes operating in a favorable chemical environment.

(2) Anode performance in the field shows a progressive trend toward the laboratory level of performance, as the improvements in anode composition and anode environment indicated by the laboratory investigation are incorporated into field practice. While certain of the field tests show anode performance approaching that observed in the laboratory, in general, the field data currently available do not cover a sufficient number of tests, nor are the tests of sufficient duration to permit specific conclusions.

References

1. H. W. Wahlquist, Corrosion, **1**, 119 (1945).
2. O. C. Mudd, Petroleum Industries Electrical Association Annual Meeting, Houston, Texas, May 5-6, 1943.
3. G. R. Olson, p. 56, Proceedings, First Annual Meeting of the National Association of Corrosion Engineers, Houston, Texas, April 10-12 (1944).
4. Porter Hart and Yale W. Titterington, Corrosion, **1**, 59 (1945).

Editor's Note: Discussion of this paper is scheduled to appear in a later issue of this magazine.

Carbon and Graphite for Corrosion Resistance

By C. E. Ford

National Carbon Co., Inc., Cleveland, Ohio

FOR MANY YEARS carbon and graphite products have been vital tools in the electrical, electrochemical and electrothermal industries; but their wide application as corrosion-resistant materials of construction is a more recent development.

A very brief description of the process of manufacturing carbon and graphite will aid in understanding the nature and properties of the materials. The basic raw material is some form of elementary carbon, such as anthracite coal or petroleum coke. After calcining at high temperatures to drive off the volatile constituents, the basic carbon material is sized and mixed in the proper proportion of fine and coarse particles with pitches and tars. The heated plastic mass is then formed by pressure extrusion or molding to the shape and size required. The "green" piece is baked under suitable controlled conditions in a reducing atmosphere at a temperature of approximately 1800° F. During the baking process, the pitches and tars are carbonized and the volatile parts driven off, leaving a hard, slightly porous, homogeneous piece of elementary carbon. Graphite is produced by properly packing carbon stock in a graphitizing furnace and, through the electrical resistance of the pack, subjecting the carbon to temperatures of 4800°-5400° F. This causes the carbon to undergo a molecular metamorphosis and become graphite. Carbon and graphite are both elementary carbon, but are allotropic forms of the element.

The unique combination of chemical and physical properties found in carbon and graphite makes them particularly suitable for corrosion-resistant structural materials for the process industries. Both materials are chemically inert in practically all acids, alkalies and organic compounds except those of strong oxidizing character. They combine reasonable strength with light weight (approximately the same density as magnesium). Both materials, but particularly graphite, can be machined easily and fabricated into a wide variety of shapes and sizes. Their low coefficients of thermal expansion make them practically immune to thermal shock. A wide range of thermal conductivity is available since carbon is a fairly good insulator, whereas graphite is a better conductor of heat than many metals. Of the more common materials of construction only copper, silver, aluminum and magnesium have thermal conductivities higher than graphite. In air, the threshold oxidation temperature of carbon is about 660° F. and that of graphite is approximately 840° F., but both materials are stable in inert or reducing atmospheres at any commercial temperature. Carbon has no melting point,

but volatilizes at a temperature of about 6500° F.

Carbon and graphite are inherently porous, having a porosity of 15-25 percent and are therefore slightly permeable to fluids even under very low pressures. For many structural applications this property is not desirable, and methods have been developed for rendering the base stocks impervious by impregnating them with chemically resistant, thermal setting, synthetic resins. These impervious forms of carbon and graphite are designated by their trade names as "Karbate" materials. For clarity of discussion of the applications of carbon and graphite as corrosion resistant materials of construction, it is therefore desirable to divide them into two groups—the permeable or regular materials, and the impervious materials. See Table I.

Structural Carbon and Graphite

The permeable forms of carbon and graphite have been used in the chemical industry for many years. Because of their porosity, these materials usually are employed under very low pressure conditions which will produce little, if any, seepage; or they are used in combination with impervious membranes or backing materials. As a structural material, they may range in size from large blocks 30 x 24 inches or 40 inches diameter in cross section, weighing as much as 7,000 pounds, to tiny rods less than ⅛-inch in diameter.

Standard brick shapes of carbon and graphite and carbon Raschig rings for tower packing have been familiar to the chemical industry for many years. The use of carbon brick is standard practice for the lining of tanks for the pickling of stainless steel in nitric-hydrofluoric acid mixtures. They are also widely used for lining towers, reactors and digestors for caustic conditions, or where sudden temperature changes might produce thermal shock. The type of mortar and exact lining construction will, of course, vary with the application. Because the cement or mortar joints are frequently the greatest source of trouble in brick lining installations, it is often desirable, where design conditions permit, to employ large block construction to keep the number of cement joints to a minimum. A good example of large carbon block construction is found in the all-carbon electrostatic precipitator illustrated in Figure 1. Such units are widely used to knock down mists in sulfuric and phosphoric acid pro-

TABLE I

Typical Physical Properties of Carbon and Graphite Products

	Plain Carbon	Plain Graphite	Impervious Carbon	Impervious Graphite	Porous Carbon	Porous Graphite
Apparent Density, lbs./cu. ft.	93-103	94-105	110	117	65	65
Strength, lbs./sq. in.:						
Tensile	400-1500	450-900	1800	2400	80-190	50-100
Compressive	2000-10000	3000-9000	10500	10000	300-850	270-500
Transverse	800-3000	1500-2800	4400	4800	160-600	140-250
Specific Resistance, ohms/in.[3]	0.0018	0.0004	0.0016	0.0034	0.0070	0.0012-0.0020
Thermal Expansion Coefficient /°F.	0.12-0.20x10^{-5}	0.05-0.12x10^{-5}	0.30x10^{-5}	0.23x10^{-5}	0.27x10^{-5}	0.21x10^{-5}
Thermal Conductivity B.T.U./(hr.) (sq. ft.) °F./(ft.)	3-6	70-94	3	75-85	1-1.5	20-50

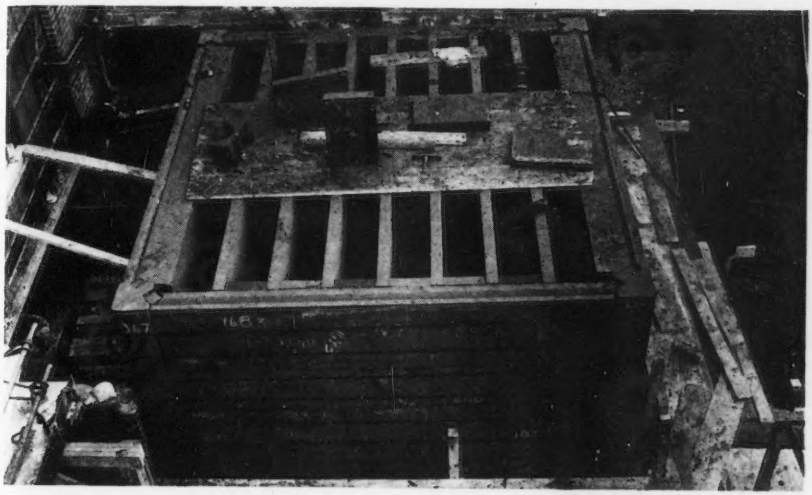


Figure 1—All-carbon electrostatic precipitator in process of erection.

duction and may be as large as 21 x 16 feet in plan and 26 feet high. The walls are carbon slabs 30 inches deep and up to 12 inches thick. Twelve feet long, 13 inches O.D. x 10 inches I.D. carbon precipitator tubes are supported from 30-inch deep carbon beams, and the roof and floor are also constructed of lighter carbon slabs. A carbonaceous type cement is employed, which sets up to produce an essentially monolithic carbon structure. All parts are pre-machined, resulting in rapid and easy erection with a saving of time and money.

Typical of large graphite block construction is a phosphorus burner tower installed by the Tennessee Valley Authority. This tower, with a capacity of one ton of phosphorus per hour, is approximately 16 feet in diameter and 30 feet high. The graphite wall blocks are 10 inches square in cross section by 30 inches long. The outside surfaces are formed on a radius to conform to the 16-foot diameter. Very thin synthetic resin cement joints are used and the tower is designed to withstand a 90 m.p.h. wind load. Although the theoretical flame temperature at the burner is 2700° F., the inside wall temperature of the graphite tower is maintained at less than 400° F. by cascading cooling water down the outside of the tower. This is a particularly spectacular demonstration of the high thermal conductivity of graphite.

The illustrations mentioned do not, of course, begin to cover the field of applications, but serve to illustrate the wide possibilities of carbon and graphite construction.

Ground Anodes

Of special interest to corrosion engineers is the use of carbon and graphite as ground anodes in the cathodic protection of metallic structures against electrolytic corrosion. Carbon ground anodes have low elec-

trical resistance, moderate first cost and a low rate of electrolytic decomposition. As compared to a scrap metal ground bed, carbon theoretically is consumed at only one-ninth the rate of iron. Carbon anodes are not affected by the purely local action of soil solutions, and in some systems where soil conditions are favorable there is practically no consumption of carbon anodes even after years of use. Ground anodes are available in two, four, and six-inch standard diameters by 80 inches long. One end of the rod is impregnated for a length of several inches to prevent the entrance of moisture, and a three-foot length of waterproof, insulated, flexible copper cable is firmly secured to that end of the rod, providing a permanent connection of low electrical resistance. (See Figure 2.) Ground rods also can be supplied with threaded ends to permit assembling in continuous rods of any desired length for deep hole installation.

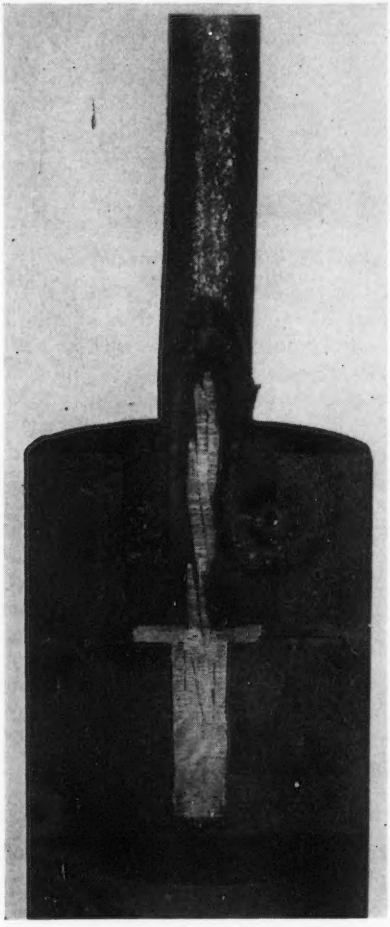


Figure 2—Sectional view of carbon ground anode showing cable connection.

Carbon anodes are recommended where soil conditions are less severe, since they are lowest in first cost. Graphite anodes are more resistant to electrolytic decomposition than carbon and are recommended for adverse soil or water conditions. For the most severe conditions, graphite anodes are given a special treatment which further increases their resistance to electrolytic action. This is the most durable type of anode available for cathodic protection service.

Porous Carbon and Graphite

The inherent porosity of carbon and graphite is used to good advantage in the manufacture of "Carbocell" porous carbon and "Graphicell" porous graphite, controlled permeability materials having a porosity of 48 percent or about double that of the regular forms of carbon and graphite. These materials have found extensive application in the dispersion of gases in liquids, filtration and humidification. Table II lists

the more important properties of porous carbon and graphite and illustrates the wide range of permeability and pore size offered by the six available grades. Table I showed that these materials are not as strong as the regular forms, but they possess practically all of the other advantageous chemical and physical properties of carbon and graphite.

Diffusers are available in a number of standard shapes and sizes (Figure 3) and are used advantageously in gas absorption, stripping and scrubbing, steam sparging and similar processes where it is desirable to disperse the gas in the form of very small bubbles (Figure 4).

TABLE II

Average Properties of Porous Carbon and Porous Graphite

Grade	Water Permeability Gal./sq. ft. /min. at 5 lbs./sq. in. Pressure (1)	Air Permeability Cu. ft./sq. ft/ min. at 2" HeO Pressure (2)	Pore Diameter (Inches)	Filter Action Minimum Diameter Particle Retained (Inches)
60.....	14	..	0.0013	0.00047
50.....	30	..	0.0019	0.00079
40.....	45	4.0	0.0027	0.00098
30.....	80	8.5	0.0039	0.00173
20.....	120	17.0	0.0055	0.0030
10.....	175	33.0	0.0075	0.0059

(1) Water at 70° F. 1 in. thick sample.
(2) Expressed at 70 °F. and 760 mm. Hg. pressure. 15 percent relative humidity. 1 in. thick sample.

They are particularly suitable for aeration equipment in aerobic fermentations since they may be sterilized by the direct introduction of

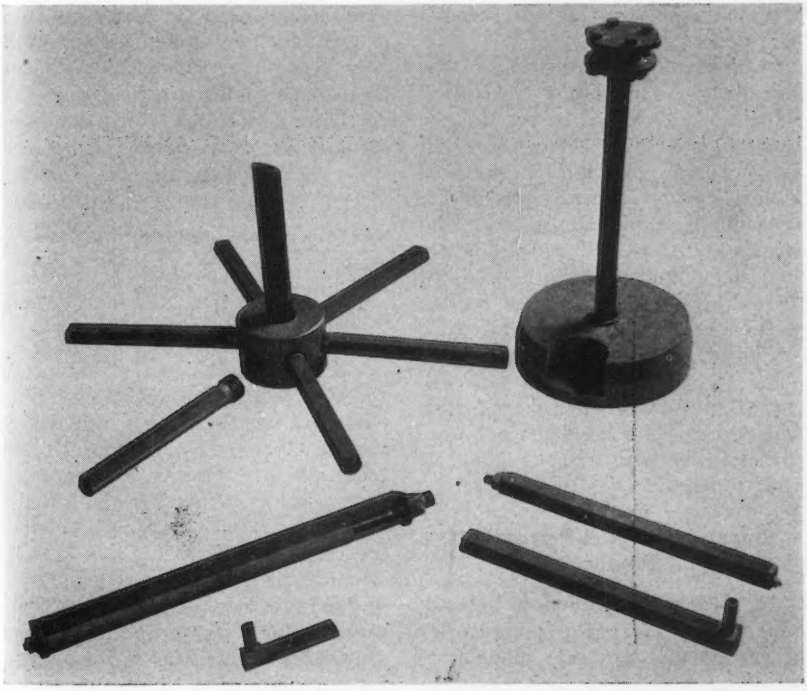


Figure 3—Standard porous carbon diffuser elements.

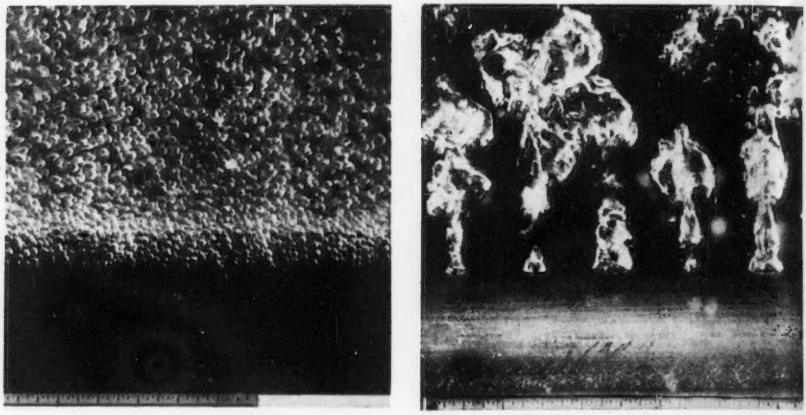


Figure 4—High speed photographs showing the comparative size of air bubbles produced by a porous carbon diffuser and a perforated pipe submerged in water.

live steam without fear of thermal spalling.

Filter elements are usually in the form of open or blind end tubes, plates and fabricated leaves. Figure 5 shows a typical corrosion-resistant type of filter employing vertical porous carbon tubes. Such filters are widely employed on acid and caustic solutions. Filters of slightly modified construction are used for the removal of solids from molten sulfur. Leaf type filters are also available for processes requiring the recovery of the solids removed. Filtration of some of the lighter metals and molten salts has been achieved successfully with porous graphite filter tubes.

Impervious (Non-Permeable) Products

As previously mentioned, impervious materials are the plain forms of carbon and graphite made non-permeable to fluids under pressure by impregnation with thermal setting, synthetic resins. By selecting the proper resin, equipment constructed from these impervious materials can be utilized under practically all the corrosive conditions which the basic stock will endure. Table III lists the three types of resin impregnants currently used and the grade designations. Grades No. 18 and No. 28 materials are limited to operating temperatures below 250° F., but the other grades may be used at operating temperatures as high as 340° F. Because of its combined properties of good machinability and high thermal conductivity, graphite is used almost exclusively as a base stock for manufacturing these impervious materials.

TABLE III

Base Stock	Resin Impregnant	Grade Designation
Carbon	Furfural	No. 18
	Phenolic	No. 12
	Modified Phenolic	No. 11
Graphite	Furfural	No. 28
	Phenolic	No. 22
	Modified Phenolic	No. 21

TABLE IV

Impervious Graphite Stock—Corrosion Resistance

(Satisfactory use of these materials is not limited to the chemical reagents shown in this table)

Chemical Reagent	Concentrations Up To (Percent)	Temperatures Up To (°F.) (See Note 1)	Recommended Grade	
			Number Material	Cement (See Note 2)
Acids:				
Acetic Acid	All	Boiling	28	14
Acetic Anhydride	100	Boiling	22	14
Arsenic Acid	All	Boiling	28	14
Boric Acid	Saturated	Boiling	28	14
Carbonic Acid	Saturated	Boiling	28	14
Chromium Trioxide, aq. soln.	10	200	28	14
Chromium Trioxide, aq. soln.	40	Room	21	14
Chromium Trioxide, aq. soln.	40	200	(21)	(14)
Citric Acid	All	Boiling	28	14
Formic Acid	All	Boiling	28	14
Hydrobromic Acid	All	Boiling	22	14
Hydrochloric Acid	All	Boiling	28	14
Hydrofluoric Acid	48	Boiling	21	14
Hydrofluoric Acid	48–60	185	21	14
Hydrofluoric Acid	Over 60	....	Not Recommended	
Hydrogen Sulphide-Water	Saturated	Boiling	28	14
Lactic Acid	All	Boiling	28	14
Nitric Acid	10	185	21	14
Nitric Acid	10–40	140	21	None
Nitric Acid	Over 40	....	Not Recommended	
Oleic Acid	All	Boiling	28	14
Oxalic Acid	All	Boiling	28	14
Phosphoric Acid	85	Boiling	28	14
Stearic Acid	All	Boiling	28	14
Sulphuric Acid	25	Boiling	28	14
Sulphuric Acid	25–75	275	22	14
Sulphuric Acid	75–96	176	21	(14)
Sulphuric Acid	Over 96	....	Not Recommended	
Tartaric Acid	All	Boiling	28	14
Alkalies:				
Ammonium Hydroxide	All	Boiling	21	15
Monoethanolamine	All	Boiling	28	15
Sodium Hydroxide	10	131	21	15
Sodium Hydroxide	10–67	257	21	15
Sodium Hydroxide	67–80	275	21	15
Tetramine C	All	Boiling	21	15
Salt Solutions:				
Ammonium Thiocyanate	All	Boiling	22	14
Arsenic Trichloride	100	230	28	None
Cupric Chloride	All	Boiling	28	14
Ferric Chloride	All	Boiling	21	14
Ferrous Chloride	40	Boiling	22	14
Ferrous Chloride	Over 40	Boiling	28	14
Ferrous Sulphate	All	Boiling	28	14
Manganous Sulphate	All	Boiling	28	14
Nickel Chloride	All	Boiling	28	14
Nickel Sulphate	All	Boiling	28	14
Phosphorous Trichloride	100	Boiling	28	14
Sodium Chloride	All	Boiling	22	14
Stannic Chloride	All	Boiling	28	14
Sodium Hypochlorite	5	Room	21	8
Zinc Ammonium Chloride	All	Boiling	22	8
Zinc Chloride	All	Boiling	22	8
Halogens, Air, Water				
Air	....	340	28	14
Bromine	100	....	Not Recommended	
Bromine Water	Saturated	....	22	14
Chlorine—Dry	100	Room	28	14
Chlorine Water	Saturated	Room	21	14
Iodine	100	....	Not Recommended	
Fluorine	100	....	Not Recommended	
Steam	100	340	22	14
Water	100	Boiling	28	14

(Continued)

TABLE IV (Continued)

Chemical Reagent	Concentrations Up To (Percent)	Temperatures Up To (°F.) (See Note 1)	Recommended Grade	
			Number Material	Cement (See Note 2)
Organic Solvents:				
Acetone	100	Boiling	28	14
Amyl Alcohol	100	Boiling	28	14
Aniline	100	Boiling	28	None
Benzene	100	Boiling	28	14
Butyl Alcohol	100	Boiling	28	14
Butyl "Cellosolve"	100	Boiling	28	14
Carbon Tetrachloride	100	Boiling	28	8
"Cellosolve"	100	Boiling	28	14
Chlorethylbenzene	100	257	28	8
Chloroform	100	Boiling	28	14
Dowtherm	100	340	28	14
Dioxan	100	Boiling	28	14
Ethyl Alcohol	95	Boiling	28	14
Ethylene Dichloride	100	Boiling	28	14
Ethyl Mercaptan-Water	Saturated	Boiling	28	14
Freon 11 and 12	100	Room	28	14
Gasoline	100	Boiling	22	14
Glycerine	100	340	21	14
Hydrazine Hydrate	85	257	28	8
Isopropyl Acetate	100	Boiling	28	14
Isopropyl Alcohol	100	Boiling	28	14
Isopropyl Ether	100	Boiling	28	14
Kerosene	100	Boiling	22	14
Mannitol	All	Boiling	28	14
Methyl Isobutyl Ketone	100	Boiling	28	14
Methyl Alcohol	100	Boiling	28	14
Monochlor Benzene	100	Boiling	28	8
Octyl Alcohol	100	Boiling	28	14
Paradichlorbenzene	100	Boiling	28	8
Paraldehyde	100	Boiling	28	14
Tetrachlorethane, Sym.	100	Boiling	28	8
Trichlorethylene	100	Boiling	28	8

Recommendations in parentheses should be used with caution.

Note 1: The recommended maximum operating temperature of No. 28 material is 250 °F. Where boiling points exceed this, substitution of No. 22 grade is ordinarily satisfactory. Fluids above the maximum recommended temperatures may be handled if sufficient cooling is provided to maintain a safe stock temperature.

Note 2: In general, for field use substitute No. 15 cement for No. 8.

Equipment is usually fabricated from the mentioned types of stock by cementing the parts together. In this way, large tanks or towers are built up from slabs of impervious stock, tubes are sealed into their tube sheets, pumps are assembled, etc. The bonds normally are stronger than the stock. A variety of bonding agents has been employed, but by far the best are the special cements whose development has paralleled that of the resin impregnants. Cements designated as Numbers 8, 14 and 15 are quite similar in chemical makeup and corrosion resistance to the impregnants in the order named. Number 8 cement is used extensively in factory assembly and may be shipped distances up to about 500 miles under refrigeration. The others are two-package cements with much better keeping qualities. These are particularly valuable in the field for final assembly and repair work. All three bonding materials will set up at room temperatures, but the curing time may be shortened by application of heat.

To give a more complete picture of the resistance of these stocks and cemented joints to various corrosive solutions, Table IV has been prepared. Recommended grades are for commercial use. A few recommendations are given in parentheses in the

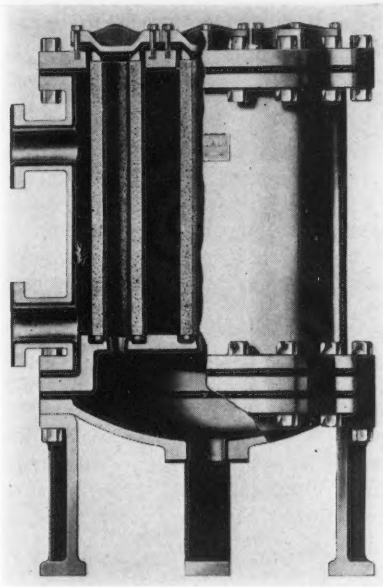


Figure 5—Typical corrosion resistant filter employing porous carbon filter tubes.
(Courtesy of R. P. Adams Co., Buffalo, New York.)

table. These usually represent conditions of uncertain service, but ones under which these products have proven to be commercially useful by comparison with other available materials. The table has been condensed by omitting recommendations for mixtures. Brief mention must be made, however, of successful installations in mixed acids—particularly hydrofluoric with other acids, pickling baths, plating solutions, rayon spin bath, organic mixtures, etc. Most of these may be predicted from the constituent ratings in the table.

As a general rule, the maximum working pressure recommended for standard equipment of this type is 75 lb./sq. in. gauge hydrostatic pressure, or 50 lb./sq. in. gauge steam pressure. Under certain conditions, or with special design, appreciably higher pressures may be used.

Heat Transfer Equipment

These materials, possessing the unusual combination of chemical inertness and high thermal conductivity, logically find their principal applications in the fabrication of heat transfer equipment for corrosive fluids. A variety of types of such equipment is manufactured, ranging from simple immersion type heat exchangers to relatively large tube bundle units. Figure 6 shows four standard designs of immersion type heat exchangers. The top two units are two of the four styles of the

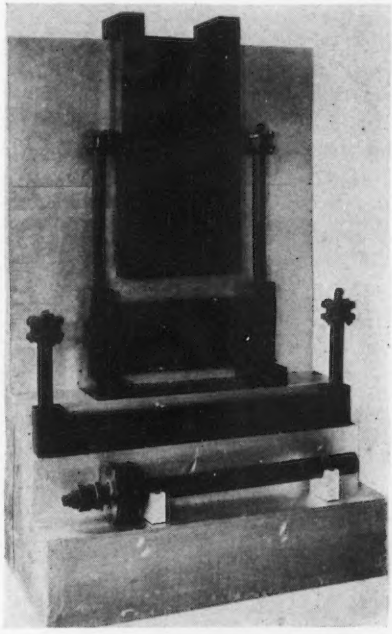


Figure 6—Typical immersion type heat exchangers.

plate type heat exchangers which derive their name from the plate elements used in their construction. The plates are provided with tubular channels for the passage of the heating or cooling medium, and their outer surface is corrugated to attain maximum heat transfer area. The units are cemented together to form exchangers offering effective external surface areas from 3.8 to 56.0 square feet. Standard designs, with various types of mountings and connections, are available to meet practically any installation requirement. Plate type exchangers are particularly resistant to mechanical shock, and are recommended for such operations as the cleaning, pickling or plating of metal objects where the work is moved around in the tanks. The two pipe coil, second from the bottom of the picture, is typical of this type of pipe coil construction. The bottom element is the well known "bayonet" or candle type heat exchanger.

Figure 7 illustrates a newly developed sectional cascade cooler. A complete cooler assembly is quickly and easily erected from only four standard items in five pipe sizes ranging from one to four inches. Single pipe cooler sections nine feet long are stacked to form a series flow vertical bank and are held in place by steel tie rod assemblies which form a rigid supporting structure. A standard steel water distributor, fitting all five cooler sizes, is

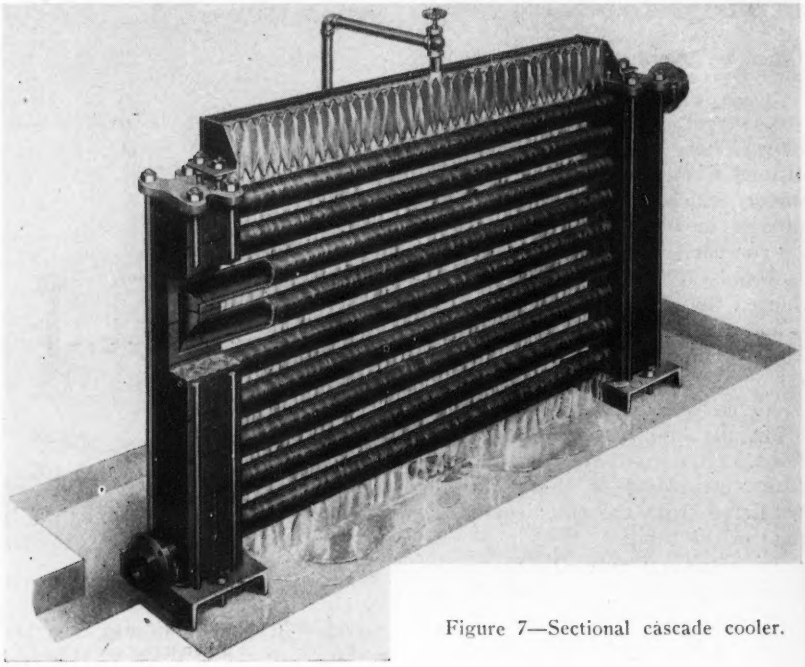


Figure 7—Sectional cascade cooler.

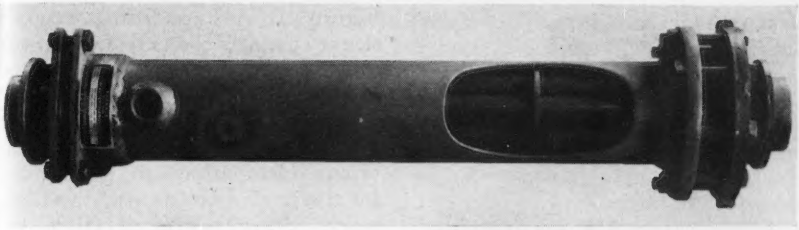


Figure 8—Standard 7-tube shell and tube exchanger.

mounted on the tie rod assemblies and can be accurately adjusted to assure uniform cooling water distribution over the pipe. Maximum effective external surface areas of approximately 120 square feet are available in all sizes in the maximum recommended cooler height of six feet.

Shell and tube heat exchangers are fabricated from impervious graphite in a wide range of sizes and styles. Figure 8 shows a small standard unit employing seven one-inch I.D. tubes available in three, six and nine-foot lengths. Large tube bundles may provide as much as 600 square feet of external surface area. Although metal shells are commonly used, shells with both fixed and floating head construction, baffles, tie rods, etc., made of impervious graphite, are employed where it is desirable to handle corrosive fluids on the shell side of the exchanger.

In addition to the types of heat transfer equipment described in detail above, concentric-type exchangers with both metal and impervious graphite jackets, sheathed electric heating elements and submerged gas heaters are fabricated from these materials.

Pipe and Fittings—Valves and Pumps

Pipe is made of these materials in 10 standard sizes from one inch to 10 inches I.D., and heat exchanger tubing in ½, ¾, and ⅞-inch I.D. Pipe lengths are joined together by couplings, flanges, elbows and other fittings made from the same material (Figure 9). Permanent connections

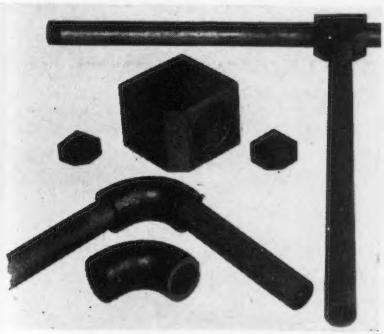


Figure 9—Typical pipe and fittings.

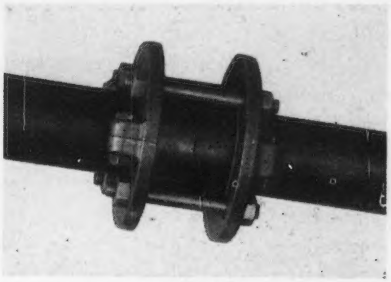


Figure 10—Flange connection.

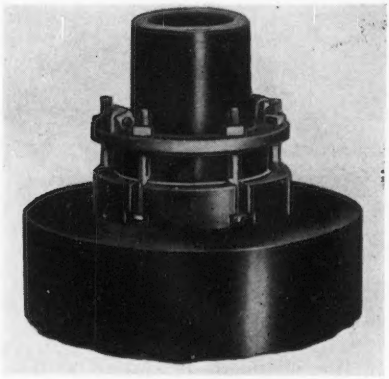


Figure 11—Slotted coupler equipment connection.

are made by threaded joints cemented in place. Several types of connections that permit disassembly are available. The standard flange connection is of the modified Van Stone type as illustrated in Figure 10. It is particularly useful in joining this pipe to iron, ceramic, plastic or other types of pipe. A special form of Van Stone flange is the factory assembled slotted coupler for making close coupled connections to tanks, towers, etc. As shown in Figure 11, slots in heavy sections of the stock provide purchase for tie bolts to pull up the same type of split-metal ring as used in the Van Stone flange.

A flexible pipe coupling that may be assembled and disassembled with the ease of a flanged joint is shown in Figure 12. A loose-fitting external sleeve connects the two pipe sections to be joined. Specially shaped synthetic rubber gaskets seal the joint and provide flexibility. Flexible pipe couplings are used in many piping installations to compensate for thermal expansion, misalignments, or excessive vibration. For submerged joints, flexibility may be provided by the use of special joints (Figure 13). A syntehtic rubber collar with ribs inside and out forms the flexible seal, which will tolerate up to 5° misalignment. The collar is usually cemented to the pipe and socket. These connections are now limited to one, one and one-ha and two-inch pipe sizes.

Globe valve are available in one inch and two inch sizes (Figure 14). All parts, with the exception of the packing and the metal hand wheel, are made of impervious graphite stock. The through-bolting feature reduces the size of the valve and makes it easy to install. Operating pressures up to 50 lb./sq. in. are recommended. Provision is made for inserting a steam heating adapter in the bottom when the handling of

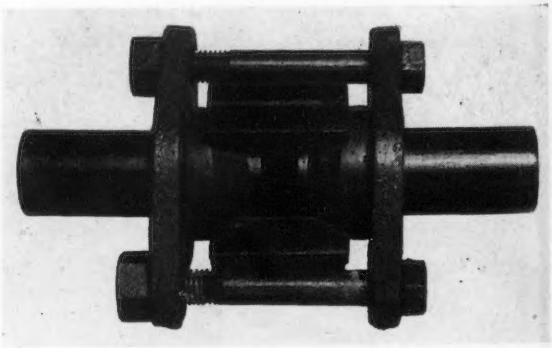


Figure 12—Flexible pipe coupling.

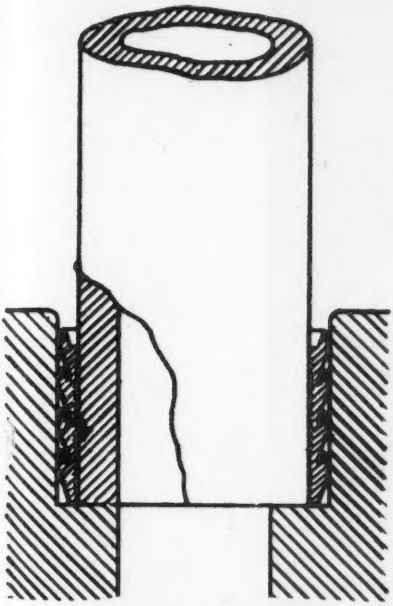


Figure 13—Special joint.

highly viscous or saturated solutions so requires. The high thermal conductivity of the graphite parts assures uniform heating. Valves of the well known Saunders type are also available up to four-inch size.

Table V lists the sizes and performance of the three standard sizes of centrifugal pumps. They are of the single stage, semi-enclosed impeller type and employ an external carbon to carbon rotary seal (Figure 15).

TABLE V
Model A Pumps

Size	NORMAL RATING			
	1735 r.p.m.		1150 r.p.m.	
	Gallons per Min.	Head in Feet	Gallons per Min.	Head in Feet
3	55	57	50	22
4	100	107	80	44
5	220	52	180	22

Towers

Standard tower sections are fabricated in sizes up to 48 inches I.D. The method of manufacture of the sections depends upon their size as detailed in Table VI. Molded sections are not dependent upon cement joints and, where the proper size is available, are generally preferable to polygonal sections. Tower sections are individually gasketed

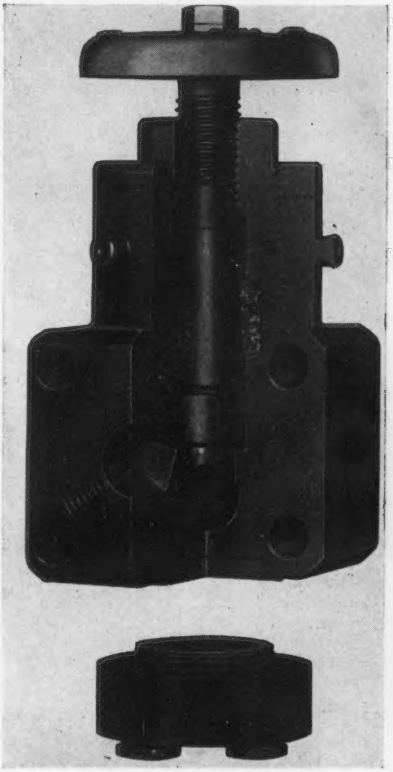


Figure 14—Globe valve.

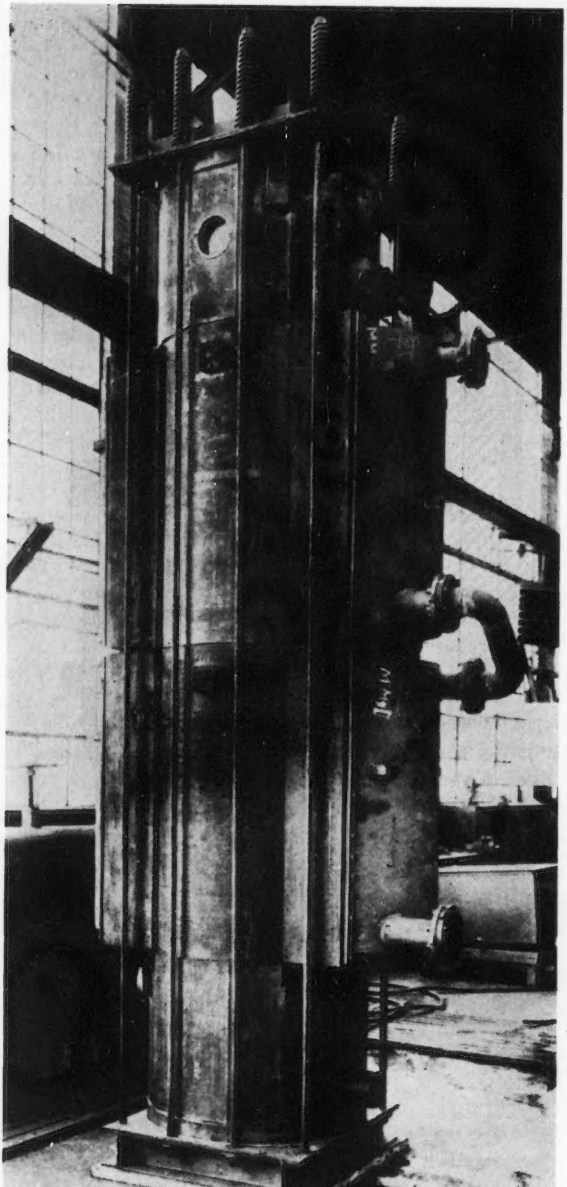


Figure 16—Standard tower construction adapted to horizontal tube type HCl absorption equipment.

TABLE VI
Standard Tower Sections

Nominal Size In.	ROUND MONOLITHIC			POLYGONAL Fabricated by Cementing Slabs to Form Multiside Section			
				Across Flats			
	O.D. In.	I.D. In.	Length In.	O.D. In.	I.D. In.	Length In.	No. of Sides
12	16	12	64				
16	20	16	64				
19	24	19	40	23	19	51	10
22	27	22	40	30	25	51	12
33	38	33	40	38	32	51	14
40	..	..	..	46	40	51	18
48	..	..	..	54	48	51	20

and held together by full length, spring loaded steel tie rods as shown in Figure 16.

Packed towers, plate towers employing impregnated graphite plates and bubble caps, or spray towers are easily fabricated.

Combinations of various standard items of equipment can be arranged to handle complete unit processes such as the absorption and stripping of hydrogen chloride, the dilution of sulfuric acid or caustic with continuous removal of the heat of dilution, and a large number of similar operations requiring corrosion-resistant, high heat transfer materials of construction.

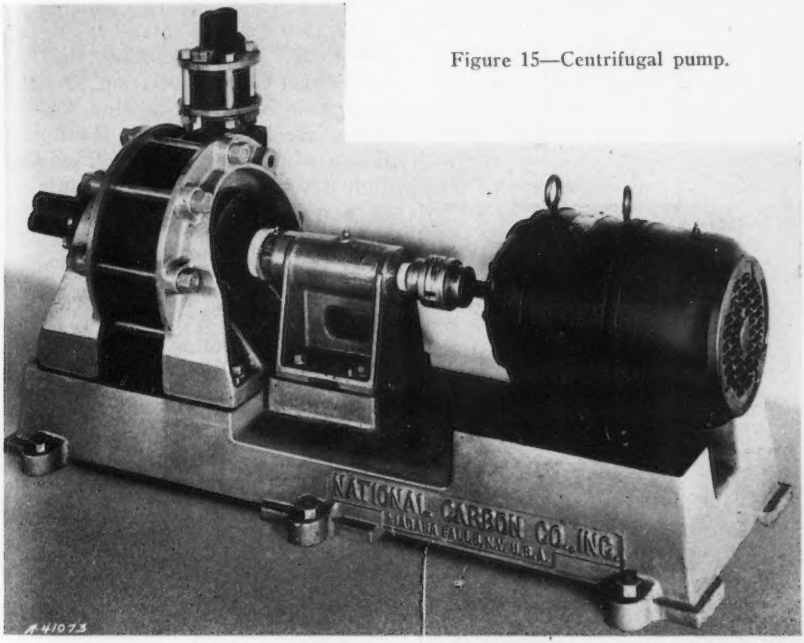


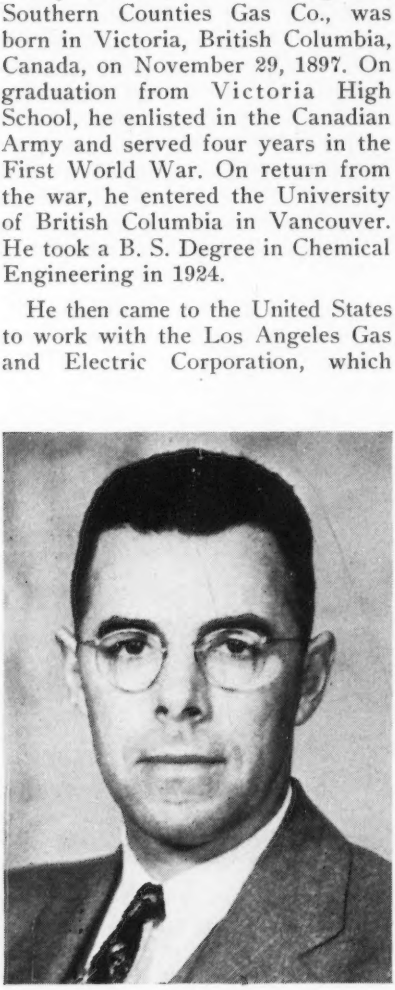
Figure 15—Centrifugal pump.

1946-47 Directors of N.A.C.E.

This month we complete the series of personal sketches on the 1946-47 members of the National Association of Corrosion Engineers, Board of Directors. Information on other members of the Board appeared in September.

Guy Corfield, Research Engineer, Southern Counties Gas Co., was born in Victoria, British Columbia, Canada, on November 29, 1897. On graduation from Victoria High School, he enlisted in the Canadian Army and served four years in the First World War. On return from the war, he entered the University of British Columbia in Vancouver. He took a B. S. Degree in Chemical Engineering in 1924.

He then came to the United States to work with the Los Angeles Gas and Electric Corporation, which later became Southern California Gas Company. He was employed first as chemist and now holds title of research engineer. He became a naturalized citizen of the United States in 1930. His work has been concerned with internal and external corrosion of metallic equipment, with particular emphasis on external pipeline corrosion.



GUY CORFIELD

He is an active member of the American Gas Association, the Pacific Coast Gas Association, and the California Natural Gasoline Association. He has served as Technical Editor of *Gas Magazine,* a Fuel Gas Industry trade journal, for a number of years. Mr. Corfield has been on the Board of Directors of N.A.C.E. since its start and is now a director representing active members.

Lewis F. Scherer, Director of Region 5 and member of the Executive Committee of the National Association of Corrosion Engineers, was born in Ottawa, Illinois, in 1901, and spent his boyhood days there. He left Illinois during his high school years to work for the state highway department in Arizona and later for the Midwest Oil Company at Casper, Wyoming.

Entering the University of Illinois, he received a degree in Mechanical Engineering in 1925. At Illinois he was on the varsity football team and was also a member of

S. A. E., Honorary Mechanical Engineering fraternity.

After leaving college, he was employed by Fairbanks-Morse Company of Beloit, Wisconsin, as a research and development engineer. In September of 1928, he came to the Texas Pipe Line Company in Houston as a designer-draftsman. At that time pipelining activities were just getting started in the coast country. He was active in the engineering and development of the Texas Pipe Line Company's system and became assistant chief engineer in 1932.

He was loaned to the War Emergency Pipe Line as special assistant to the chief engineer in design and specifications in 1942. He later became Station Construction Superintendent and then Chief Engineer. In June of 1944 he went to California in charge of construction of a pipe line to serve the United States Navy. After the end of hostilities, he returned to the Texas Pipe Line Company. He became chief engineer there in 1945, a position he now holds.

LEWIS F. SCHERER

He has been active in corrosion control work for more than a decade, ever since 1934. In 1935 he helped organize the Mid-Continent Cathodic Protection Association. Work of this organization was delegated later to the A.P.I. and the P.I.E.A. He is now chairman of the corrosion sub-committee of the AP.I. and holds membership in numerous other A.P.I. Committees. He is also a member of the American Welding Society and the Society of Automotive Engineers.

L. G. Vande Bogart, Research Engineer in the Research and Development Laboratories, Crane Company, was born in Sheboygan Falls, Wisconsin, on January 29, 1892. Mr. Vande Bogart graduated from Sheboygan Falls High School in 1909 and has attended Lawrence College, Valparaiso University and the University of Chicago. He joined the Crane Company in 1923 as Analytical Chemist, advanced to Assistant Chief Chemist, and then to his present position in 1939. Corrosion of valves and piping has been his chief concern for the past fifteen years. Mr. Vande Bogart is active in a number of technical and professional societies. He was the first Chairman of the Corrosion Division of the

L. G. VANDE BOGART

Electro-Chemical Society, Inc. He is a delegate on the Chicago Technical Societies Council, is a member of the Corrosion Hand-Book Editorial Board, and is First Vice President of Chicago Chemists Club.

Frederick A. Hough, Executive Engineer in charge of Construction and Operations, Southern Counties Gas Co., was born in Tempe, Arizona, on March 6, 1902. He graduated from the California Institute of Technology in 1924, and then entered the employ of the American Potash and Chemical Company at Trona, California. In 1925 he was employed by the Southern Counties Gas Company of California as a Research Engineer. His work with this company was, for a number of years, concerned primarily with corrosion studies, including investigations of the suitability of copper pipe for use in gas distribution systems in corrosive soil, and the cathodic protection of gas transmission lines. Mr. Hough is now a member of the Board of Directors of the Southern Counties Gas Company and is its executive engineer in charge of construction and operations. He has served on the board of directors of the Pacific Coast Gas Association and as Chairman of its Technical Section. He is now a member of the Pipe Coating and Corrosion, Construction, and Maintenance and Pipeline Flow Committees of the American Gas Association. Mr. Hough is N.A.C.E. Director representing the West Coast Region.

FREDERICK A. HOUGH

RUSSELL A. BRANNON

Russell A. Brannon, senior corrosion engineer and assistant to the Assistant General Superintendent at the Humble Pipe Line Company, was born at Merit, Texas, December 22, 1902. He grew up on a farm, getting his elementary education in Merit and Dallas. He attended the University of Texas, studying chemical engineering and business administration. He received a Bachelor of Business Administration Degree in 1928.

He was employed by Humble Pipe Line Company shortly after graduation and has worked up to his present position. In 1933 he married Mattie Lou Perry, and they have a five-year-old daughter.

Mr. Brannon has been associated with the National Association of Corrosion Engineers since it was organized, serving as its first president.

Ivy M. Parker, Senior Engineer, Plantation Pipe Line, was born in Quay County, New Mexico, on September 11, 1907. On graduation from Tucumcari High School, she attended West Texas State College and took a B. A. Degree in 1928. During her second college year she won a Garvan Essay Prize in Chemistry. She received her M. A. and Ph.D. at the University of Texas. She taught one year at Mary Hardin Baylor College, Belton, Texas, and two years at the University of Houston. She was employed by Shell Oil Company at the Houston refinery from 1936-1943 and at the J. S. Abercrombie Refinery, Old Ocean, Texas, 1943-1945. She joined Plantation

DR. IVY M. PARKER

Pipe Line in November, 1945. Her refinery work was concerned with all phases of corrosion with special emphasis on water. At present she is studying internal pipeline corrosion and pipeline efficiency. Dr. Parker is serving as Editor of CORROSION and as Chairman of the Publications Committee.

E. L. (Gene) Rolfs was born in Leavenworth, Kansas, on January 5, 1896. He spent his boyhood in Kansas City, where he attended high school. In 1917 he received his Bachelor of Science degree at the University of Kansas at Lawrence.

He worked for Standard Oil Company of Indiana for five years as an efficiency engineer at that company's refinery at Sugar Creek, Missouri. Later he joined Johns-Manville as a sales engineer in their midwest territory, with headquarters at St. Louis. Thirteen years ago Mr. Rolfs helped start the firm in which he is now a partner, Crutcher-Rolfs-Cummings, of Houston, Texas. This company deals exclusively in pipeline equipment.

Mr. Rolfs is a member of the American Petroleum Institute, the American Gas Association, and the Houston Engineers Club.

E. L. ROLFS

M. L. JACOBS

M. L. Jacobs, General Manager of Jacobs Wind Electric Company, Inc., Minneapolis, Minn., spent his early days in Montana. He attended Indiana University and took special training in radio and associated electric studies in Kansas City and Chicago. He began experimenting with electrical and generating equipment in 1922. Jacobs Wind Electric Company was organized in 1930

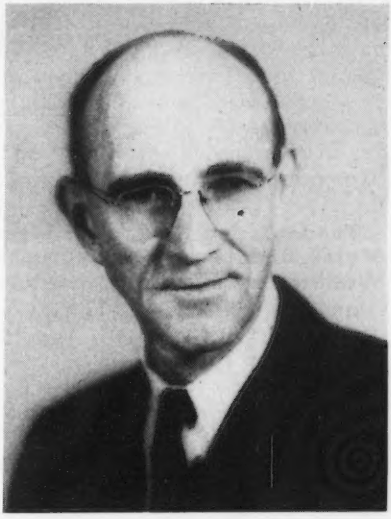
with M. L. Jacobs as manager. He, with his brother, began the manufacturing of special electric generators and generating equipment. Since 1934 Mr. Jacobs has devoted considerable time to the study and development of special generating equipment for the use in cathodic protection of pipelines. He is a Director in N. A. C. E. representing Associate Memberships.

A. N. Horne was born in Matherville, Mississippi, in 1894. He graduated from Mississippi State College with a B. S. in Electrical Engineering in 1918. From college he went directly to service in World War I as a junior officer, tank corps.

He was employed in 1919 by Cities Service Company in Mississippi. He transferred to Bartlesville, Oklahoma, later in the year as a student engineer in Doherty Training School of the old Empire Oil and Refining Company (Cities Service), and then worked in various departments.

In 1929 Mr. Horne was made Superintendent of Operations, then General Superintendent. In 1936, he became Manager and Director of Empire Pipe Line, and Manager, Storage Division, Cities Service Oil Company at Bartlesville. He served concurrently as Vice President and Director of the Texas-Empire Pipe Line Company (Oklahoma to Chicago), The Texas-Empire Pipe Line Company of Texas (East Texas to Port Arthur), the Kaw Pipe Line Company (Western Kansas), and as Director of the Texas-New Mexico Pipe Line Company.

In 1941 he served with the Technical Committee representing 11



A. N. HORNE

major oil companies developing plans for construction of a 24-inch crude oil line from East Texas to New York (National Defense Pipe Line Company.) Shortly after Pearl Harbor, Mr. Horne was called to active duty with the old General Staff Corps at Washington. He served as a Major, as Assistant G-4 Transportation. In 1942, when the Big Inch pipe lines project was revived as a government owned defense project, Major Horne returned to inactive status and was assigned to construction of War Emergency Pipelines, Inc., as vice president and general superintendent, then assistant manager, and finally as general manager, after completion of construction of the 24-inch crude and 20-inch refined products lines. He is presently with the Texas-Empire Pipe Line Company at Tulsa as Vice President and Assistant Manager.

Corrosion Abstracts

ATMOSPHERIC CORROSION

The Corrosion Behavior of Light Metal Sheets on Exposure to Weather for Six Years. P. BRENNER, Aluminum, **26,** No. 1, 13-17 (1944); J. Inst. of Met. & Metall. Abs. **13,** 11-12 (1946) Jan.

The results of an investigation of the resistance to weathering of 31 aluminum alloys are reported. Alloys, whose compositions are tabulated, were in various initial conditions (also tabulated) before exposure to the weather for six years. The tensile strengths and elongations of the specimens were examined after the full exposure and at several intermediate times. Results are shown in a series of graphs. Specimen photomicrographs of the weathered materials are reproduced. General conclusions are that plated or clad aluminum - copper - magnesium alloys in the normal age-hardened condition are scarcely affected by exposure. Moderate loss of elongation, but not of tensile strength, occurs for aluminum - magnesium-manganese, aluminum - magnesium-silicon, aluminum-manganese alloys, and aluminum and for homogeneous aluminum-magnesium alloys. Moderate loss of both elongation and tensile strength occurs for unclad aluminum - copper - magnesium and aluminum-copper alloys in the cold age-hardened state, and for clad aluminum-copper-magnesium in the hot age-hardened condition. Serious deterioration occurs for aluminum-silicon alloys and for aluminum-magnesium alloys which are heterogeneous or age-hardened.

The Corrosion of Rolled Zinc in the Outdoor Atmosphere. A. E. ANDERSON, N. J. Zinc Co. Paper before ASTM, Symp. on Atmospheric Exposure Tests on Non - Ferrous Metals, Pittsburgh, Feb. 27, 1946. ASTM Preprint (Mimeog.), 1946, 8 pp.

Results of 10-year exposure of three grades of rolled zinc are reported. Test locations included industrial and marine environment. Data on tensile strength, elongation and change of weight, as well as weight of corrosion products are presented. Rolled special high grade zinc corrodes more slowly than rolled high grade prime western zinc, especially in southern locations. Rolled zinc corrodes most rapidly in moist industrial atmospheres, and very slightly at sea coast locations, and then only when there is excessive moisture or industrial contamination in air.

Resistance to Atmospheric Corrosion of Galvanized Steel Wires and Ropes. G. SCHIKORR, Arch. Eisenhuttenwesen, **17,** No. 5/6, 147-150 (1943); J. Inst. of Met. & Metall. Abs., **12,** 359-360 (1945) Nov.

The loss of weight of galvanized steel wire and ropes was measured

after atmospheric exposure in an urban area extending over a period of several years. It was found that zinc losses were much higher in the winter than in the summer, and were proportional to the sulfur content of the atmosphere. Wire ropes were found to be much more corrosion resistant than single wires. This is due to the electrochemical protection of the outside of the rope by the less-exposed center.

The Resistance of Aluminum-Base Alloys to Atmospheric Exposure. E. H. Dix, Jr., and R. B. Mears, Aluminum Co. of America, Paper before A.S.T.M., Symp. on Atmospheric Exposure Tests on Non-Ferrous Metals, Pittsburgh, Feb. 27, 1946; ASTM, 1946, Preprint (Mimeog.), 7 pp.

A discussion of aluminum base alloy specimens exposed in A.S.T.M. 10-year exposure tests, and results of atmospheric tests by the Aluminum Research Laboratories are given. Some specimens were standard machined-to-size tension specimens, others were in form of panels 9 x 12 inches. All tests rate Alclad 17S-T as superior to other aluminum alloy sheet. Alclad 24S-T was also very resistant. Losses for 38, 28 and 53S were appreciable. Locations were industrial and marine.

A New Laboratory Experiment on Atmospheric Corrosion of Ordinary Steels and Small Amounts of Additions. E. Herzog, Metaux, Corrosion —Users, **20,** No. 236, 47-51 (1945) Apr. (In French).

Corrosion experiments were made reproducing atmospheric attack (acid). Results were obtained by alternating the corrosive effect of an atmosphere saturated with humidity, with that of an atmosphere with medium humidity (50-40 percent). The variations of humidity in the films or deposits on the surface of the steels react differently, according to the surface conditions and the composition of the steels. Effect of chromium, aluminum and silicon additions is discussed. Tables and a bibliography are given.

Transformer Corrosion. Is It Electrolytic? H. Robson, B. Sc., A.M.I. E.E., Electrical Times, **109,** 562-63 (1946) Apr. 18.

The observed facts relating to corrosion in transformers present inconsistencies, but the generally accepted theory is that acid inherent in the oil is at the root of the trouble. It is said that abnormal overheating, damp and stagnant air in substations, and insufficient ventilation in the space above the oil are conditions assisting acid development. This theory, the author points out, fails to explain the formation of oxides on the under side of the lid, the formation of the malignant growth above the surface of the liquid, the beginning of corrosion at the edges of the lid, and other observed facts. The theory here put forward is that moisture, plus electrolysis due to parasitic potentials caused by the use of metals in actual contact which are situated far apart in the table of electrochemical equivalents, is the origin of the corrosion; and that if this theory is correct, de-acidification of the oil as a means of cure is a waste of time since the acid is a product of the offending reaction, and not the cause

Treatment suggested is that the joints should be made airtight, and that if breathing is to be allowed, it should take place only through a calcium chloride or other breather in which the chemical is changed frequently. If no breather is provided, care should be taken when removing transformer lids for inspection not to use an exposed flame. Other hints are given, and the diagram included illustrates the theory.

Present Position of the (Iron and Steel Institute) Corrosion Committees Field Tests on Atmospheric Corrosion (Unpainted Specimens of Ferrous Materials). J. C. HUDSON, J. Iron Steel Inst. **148,** 161-215 (1945), Brit. Chem. Abs. BI-68 (1946) Feb.

The results of tests for five years at seven home and seven overseas stations are recorded and discussed. The primary cause of serious corrosion of ferrous materials is pollution of the air with sulfur gases. Corrosion in non-industrial, tropical or subpolar climates is generally slight in comparison with the attack at Sheffield, although in marine atmosphere corrosion may occur if a scaly rust forms on the surface. Wrought iron containing much slag is more resistant to atmospheric corrosion than either mild steel or ingot iron. Aston-Byers iron (made by mixing synthetic slag with dead-mild steel) is slightly less resistant, and wrought iron with a low slag content is more corrodible. Addition of small amounts of copper improves the corrosion-resistance of steel in the open air, but not in the railway tunnels; in general, additions of chromium, silicon, nickel and probably arsenic are also beneficial. Surface conditions usually have little influence, but machined surfaces corrode faster than sand-blasted ones. Complete descaling of mild steel, with or without copper, by weathering does not occur in less than one year in Britain, and much longer periods are necessary in mild climates. Some tests on the corrosion of zinc and hot-galvanized sheet are recorded and the results are discussed in terms of the probable life of galvanized coatings. Black sheets in general need to be 0.02 inches thicker than galvanized sheets for equivalent corrosion resistance.

Corrosion Plays Havoc with Coastal Meters, Electrical West, **96,** No. 3, 62-3 (1946) Mar.

Heavy fogs and salty atmosphere prevalent in the coastal regions are apparently the conditions which give rise to corrosion in two forms: (1), direct corrosion, particularly in aluminum alloy meter bases as a result of exposure to the damp salt atmosphere; (2), galvanic action between dissimilar metals which are in close proximity under the same atmospheric conditions. Broken glass covers, corrosion of parts to the point where they cannot be removed, and disintegration to the point of unserviceability or to the point of presenting maintenance hazard, are among the principal difficulties. In tests conducted so far, a meter with all exposed metal of aluminum, anodized by the sulphuric acid process, and then coated with air-dry lacquer, has stood up best. Such units have stood 115 hours in the salt spray booth, then 264 more hours standing wet, or have stood up four months on the test rack, without any evidence of corrosion.

BEARING CORROSION

New Synthetic Lubricants. J. C. KRATZAR, D. H. GREEN AND D. B. WILLIAMS, Paper before SAE, Detroit, Jan., 1946; Petroleum Refiner, **25**, No. 2, 127-138 (1946) Feb.

Detailed description of the characteristics of two series of synthetic lubricants developed by units of Union Carbide & Carbon Corp. The LB series are insoluble in water while the 50-HB series are soluble in water at room temperature. They are synthesized from natural or other hydrocarbon gases as raw materials and contain no petroleum oils. Discussion is mostly confined to LB series, which are used extensively in aircraft engines. Numerous tables and photographs are shown.

Inhibitors in Turbine Oils Reduce Oxidation and Prevent Rust. E. W. GARDNER, Paper before Pacific Coast Electrical Ass'n., Power, **90**, No. 3, 87-89, 140 (1946) Mar.

Results of recent ASTM tests on oils treated with inhibitors which act against both oxidation and rust simultaneously are reported, with description of apparatus used. Oils have been in service only a part of their expected lives as yet.

BOILER CORROSION

External Corrosion of Boiler Furnace Tube Walls. Steam Engineer, **15**, 9-12 (1945) Oct.; Corrosion & Material Protection, **3**, No. 1, 25 (1946) Jan.

Discusses studies made in the United States on central station boiler furnaces which burn pulverized coal and remove the ash on slag-tap principle, and in which corrosion of the furnace steel tube walls has been experienced.

The 2,000-psi Forced-Circulation Boiler at the Somerset Station of Montaup Electric Company. Power Plant Eng'g, **50**, No. 1, 76-84 (1946) Jan.

In a four-sectioned article dealing with operating history and performance, feedwater system and water conditioning, two sections are of corrosion interest:

Special Studies of the Feedwater-Steam System, by W. D. Bissel, H. E. White and B. J. Cross.

Water Conditioning for the 2000-psi Boiler, by W. W. Cerna and R. K. Scott.

Sludge analysis, scale deposits, dissolution of iron and copper in feedwater, and special water conditioning treatment are discussed.

Chemical Removal of Scale from Fire Tube Boilers. C. H. GROOM AND E. C. HARDY, Dowell, Inc., Power Plant Eng'g, **50**, No. 4, 66-67 (1946) Apr.

Effect of various thicknesses and types of scale on heat transfer in boilers, types and chemical composition of various scale deposits are discussed and a recommendation made that chemical removal procedure be chosen. Method is not described. A table aids in scale analysis.

Feedwater Treatment. E. NOVAK, Marine Eng'g & Shipping Rev., **51**, No. 4, 138-142 (1946) Apr.

The three bad effects of impure boiler water, scale corrosion and carry-over are discussed, and reports

from examples of each on ships are itemized. Water treatment is recommended.

CHEMICAL CORROSION

New U-Cast Hairpin Cooler Element. Industrial Heating, **13,** No. 2, 341 (1946) Feb.

Using experience gained during the war in producing units that cooled highly concentrated sulfuric acid from 475° F. to 175° F. or lower in making high explosives, the National Radiator Company has developed its new U-Cast hairpin cooler element for peace-time applications. The new unit is especially adapted for cooling acids or strong alkalies under extreme conditions. The new elements in these applications are submerged in the solution and the coolant, usually water, is passed through the element itself. The sections of the units are cast of gray iron highly resistant to attack from both the solution and its fumes. Coils formerly used in the acid-cooling vats of munitions manufacturers had to be completely replaced at least every three months. After months of service in the same vats, the new cast-iron elements showed no corrosion either above or beneath the liquid line. Cooling capacity and efficiency of the new elements were as satisfactory as, or better than, the coils formerly used, the plants reported.

The Intercrystalline Corrosion by Sodium Chloride of a Wrought Aluminum Alloy Containing Four Percent of Copper. Paper No. 1014. J. D. GROGAN, Nat. Phys. Lab., Teddington, England; J. Inst. Metals, **72,** Pt. 2, 133-138 (1946) Feb.

Attack by mineral acid (hydrochloric) is mainly on the grain boundaries and the alloy becomes brittle. Attack by sodium hydroxide forms round, shallow pits in the grain boundaries without embrittlement. Exposure to aerated sodium chloride may develop oxygen concentration cells; areas deficient in oxygen become anodic and the hydrochloric acid type of intercrystalline attack occurs, while areas high in oxygen become cathodic and the non-embrittling attack develops. If the alloy is water quenched, the hydrochloric acid attack occurs along certain atomic planes of the crystals; whole crystals may be dissolved while boundaries are relatively free from attack. Photomicrographs show typical results.

Accelerated Corrosion of Tin Cans in Various Types of Solid Fibre Containers. C. E. LIBBY, F. W. O'NEIL, AND A. W. NICKERSON, Canning Trade, **66,** No. 28, 12-13 (1944); J. Inst. of Met. & Metall. Abs., **13,** 13 (1946) Jan.

The object of this investigation was to compare several types of "V-boxes" for their properties in promoting or inhibiting the corrosion of tin cans. The test methods and materials are described. The results suggested that the major source of corrosion was in the box itself, perhaps being due to a chemical constituent of the pulp, such as alum, sulfur, or iron.

Lead Corrosion in Sulphur Acid Tower Systems. F. PERKTOLD AND P. M. MULLER, Chem. Techn., **17,** 1-5 (1944); J. Inst. of Met. & Metall. Abs., **12,** 359 (1945) Nov.

Types of corrosion, effect of tem-

perature and presence of air, reactions to nitric acid, are discussed. Methods of investigation are described and results with various acids and compositions of lead are tabulated.

Corrosion Reporter — Silicones. Chem. & Metall. Eng'g, **53,** No. 3, 215-216 (1946) Mar.

Successful use of silicone lubricants, coatings and insulations involving high temperature, acid and moist conditions is reported. Silicone grease is now recommended by Merco Nordstrom Valve Co. for quick-opening steam valves, is used in valves in cellulose products plants handling acid mixtures, of hydrogen chloride gas, ether, ethyl chloride, and water at 570° C.; also for plug cocks handling 50 percent caustic and 93 percent sulfuric acid. Largest proving grounds for silicone coatings are hot equipment in Midwestern oil refineries where results are hopeful.

Corrosion Problems in the Cracking of Shale Oil. G. E. MAPSTONE AND C. B. MCLAREN, Nat. Oil Proprietary, Ltd.; Petroleum Refiner, **25,** No. 2, 97-100 (1946) Feb.

On cracking, the tar bases in crude shale oil give rise to small amounts of hydrogen cyanide, part of which, in the presence of water and ammonia, is hydrolyzed to formic acid, while the remainder combines with iron products to form prussian blue. The formic acid causes corrosion in the upper section of the pressure distillate stabilizer while in other sections of the plant the presence of tar bases inhibits this form of corrosion. Corrosion at Glen Davis, Australia, is described. Installation of a countercurrent caustic soda wash between the distillate receiver and the stabilizer effects satisfactory removal of the acidic corrosive materials. Also, mild-steel tubes were replaced by stainless steel ones. Ten references are given.

Packaging of Acids and Corrosive Liquids. T. P. CALLAHAN, Chem. Inds., **58,** No. 1, 102 (1946) Jan.

Containers for acids and corrosive liquids are of four types: five-pint bottles, glass carboys, metal drums and tank cars. ICC specifications for each are described in general terms. Most universal type drum is of low-carbon open hearth or electric steel. Other drums are of nickel (ICC 5K), lead-lined steel, aluminum lined, and all aluminum drums. Stainless steel tank cars are used for shipment of nitric acid, lead-lined tanks for battery acids, phosphorous oxychloride and phosphoric trichloride. The nickel drum can be used for the last two chemical products, but cannot be used for sulfuric acid.

Chemical Plant in Germany—Corrosion Problems in the Oils and Fats Industry. Chem. Age, **54** 81-82 (1946) Jan. 19; Mond Gen. Refer. Sheet, Ser. No. 466, 14 (1946) Jan. 26.

Commenting on recent issue of reports on German industry, and with special reference to the publication, "a year or two ago," of an up-to-date book on producton of oils and fats (by R. Lude, of Mannheim), the writer makes reference, inter alia, to German experience with "special" steels and other materials in this industry. Various grades of

Remanit nickel chromium steel are mentioned as having given generally good service. "Among the copper and nickel alloys, those with about 70 nickel and 30 copper, such as Monel, are highly valued, when obtainable. They are, for example, strongly resistant to concentrated soda lye, but, according to Lude, are less satisfactory with water-clear stand oils and with certain esters." Various types of protective coatings used in the fats and oils industry are considered, also non-metallic materials.

Recent Russian Work on Corrosion. Chemical Age, **54** 5-8 (1946) Jan. 5; The Metal Review, **19,** No. 3, 9 (1946) Mar.

Corrosion resistance (stability) of different materials employed in construction of apparatus destined for fundamental Russian chemical industries, including: (a), production of halogen salts, such as chlorides; (b), sulfur compounds; (c), fluorine compounds; (d), halogen compounds of the iodo-bromine type; (e), general research on materials liable to corrosion is described.

Corrosion Studies on Electrolytic Chromium. N. HACKERMAN AND D. I. MARSHALL (Univ. of Texas), Paper before Electrochem. Soc., 89th Gen. Mtg. Birmingham, Ala., Apr. 11, 1946; Electrochem. Soc., Preprint **89,** 15, 171-180 (1946).

Electrolytic chromium stripped from its basis metal, was immersed in aqueous solutions of sodium hydroxide, hydrochloric acid, sulfuric acid, acetic acid and sodium chloride at various concentrations with the last being studied over a pH range from 0 to 11. The metal was used in both the active and passive state and the solutions, saturated either with air nitrogen or hydrogen, were maintained at 35° C. Results are reported.

Corrosion Resistance of Glass. M. S. TARNOPOL AND A. E. JUNGE, Pittsburgh Plate Glass Co., Chem. Inds., **57,** No. 7, 1112 (1945) Dec.

Test data on the corrosion of plate glass by alkaline solutions are reported. Plate glass can withstand adequately most alkaline solutions up to 150° F., and some at much higher temperatures where staining is not an important factor. Scale has little effect on corrosion rates, and appearance gives no indication of the amount of corrosion. Rates of concentration and temperatures are correlated with corrosion. Potassium compounds act slower than sodium salts, and sodium hydroxide slower than sodium carbonate and pyrophosphate.

COATINGS

Practical Problems Connected with Metallic Corrosion. U. R. EVANS, J. Birmingham Met. Soc., **24.** 228-58 (1945), Brit. Chem. Abs. BI-68 (1946) Feb.

If steel can be cleaned thoroughly, preferably by shot-blasting, excellent protection against corrosion is secured by first spraying with aluminum from a wire pistol and then painting. For uncleaned steel, promising results have been obtained by the use of inorganic cementiferous paints (composition not yet revealed) or organic paints with a polystyrene or chloro-rubber base richly pigmented with sufficient zinc dust to be electrically conduct-

ing. For cooling systems, where anodic inhibitors are known to be dangerous (they may accelerate attack if present in insufficient amounts), the use of cathodic and anodic inhibitors for alternate periods may be safe and efficient. Tests on corrosion fatigue indicate that exposure to this condition for only a short period may have a most damaging effect on the resistance of steel when subsequently exposed to simple fatigue stressing, even though all corrosion influences are then excluded.

Metal Coating by Vacuum Evaporation. F. C. BENNER, National Research Corp., Modern Plastics, **23,** No. 6, 110-111 (1946) Feb.

The vacuum evaporation method of plating metals on plastic, which originated in coating glass optical surfaces with low-reflecting materials and with metals such as aluminum, silver, gold, rhodium, chromium, etc., is described. Among metals that can be so deposited is nickel.

Antifouling Paints. R. W. MONCRIEFF, Paint Tech., **10,** No. 112, 81 (1945), Brit. Abs., BII-Ind. Organic Chem., Jan., 1946, 20.

The principles of effective formulation of paints for antifouling purposes and of the most effective paint systems are explained in the light of recent work. The results of tests on a fresh water fouling organism with organic toxins is given. A review of recent literature is included.

Lead-Coated Stainless Steel. C. C. DOWNIE, Chem. Products, **8,** No. 11/12, 81-82 (1945); J. Inst. of Met. & Metall. Abs., **13,** 54 (1946) Feb.

The process of lead coating on iron and steel, and the use of parts so protected for resisting the most strongly corrosive liquors, are briefly dealt with.

The Influence of Dissolved Tin on the Growth of *Clostridium Botulinum* in Canned Vegetables. II. Further Experiments in Plain and in Lacquered Cans. W. J. SCOTT AND D. F. STEWART, J. Council Sci., Indust. Research, Australia, **18,** No. 3, 173-180 (1945); J. Inst. of Met. & Metall. Abs., **13,** 54-55 (1946) Feb.

Corrosion results from inoculation of *clostridium botulinum* in plain and lacquered cans of various vegetables are reported.

The Protective Value of Lead and Lead-Tin Deposits on Steel. A. H. DU ROSE, The Harshaw Chem. Co., Paper before 89th Gen. Mtg., Birmingham, Ala., Apr., 1946; Electrochem. Soc., Apr., 1946, Preprint **89,** 7, Advance Copy, 101-112.

The corrosion protective values of lead and lead-tin deposits on steel are discussed. Comparisons between different methods of testing, effect of thickness of deposit and the concentration and nature of the addition agent in the plating bath are covered. Throwing power of the baths and the effect of the metal undercoat on corrosion resistance are also mentioned. Salt spray test data are included.

Influence of Alloy Elements in Steel and of Pickling Upon Porosity of Phosphate Coatings. W. MACHU, Korrosion und Metallschutz, **19,** No. 10, 269-274 (1943).

The influence of carbon, copper, chromium, nickel, molybdenum, manganese and silicon in steels upon the porosity of phosphate coatings

has been studied. The chemical composition of a steel is of minor importance for the porosity and the structural make-up of the coating. On ground surfaces, alloy elements mentioned cause a slight decrease in porosity over that shown by electrolytic iron on phosphating. The surface condition of steel is more important. By pickling, the porosity of the phosphate coating is increased considerably on electrolytic iron and on all of the carbon and alloy steels (excepting the three percent nickel steel). The corrosion resistance of phosphated iron and steel is influenced by the preliminary treatment of the surface, and the corrosion resistance of the base metal itself. Seventeen references are given.

Shipboard Corrosion Problems. K. TATOR, Ind. Lining Engineers, Pacific Marine Review, **48,** No. 1, 12-13 (1946) Jan.

Linings or coverings of resilient, rubber-like materials serve three functions: (1), they protect marine equipment from severe corrosive action of sea water, salt spray, or cargo; (2), they protect it from the abrasive action of silt, hard fuels, or solid bulk shipments; (3), they protect cargoes from undesirable contamination by iron or rust from contact with bulkheads in holds. Special virtues of these linings are their thickness (a defect in a thin film will penetrate the film, but in a lining or covering it will be entirely surrounded by sound, resistant material) and the fact that sharp projections and edges are fully protected by sheer bulk of lining material. Qualifications and uses of the following are summarized: natural and synthetic rubbers, neoprene, thiokol, vinyls, bakelites, polystyrene, vinylidene chloride and polyethylene. Parts mentioned are steel propeller shafts driving bronze wheels, and ship holds. They are also used to maintain a protective barrier over working rivet heads on lap seams.

The Use of Lead and Tin Outdoors. G. O. HIERS, National Lead Co., Paper before ASTM Symp. on Atmospheric Exposure Tests on Non-Ferrous Metals, Pittsburgh, Feb. 27, 1946; ASTM, 1946, Preprint (Mimeog.), 6 pp.

Historic uses of lead and tin outdoors are briefly outlined. Reports of the ASTM subcommittee discussing the behavior of chemical lead, antimony-lead and commercial tin, are commented upon. Losses in weight, thickness and strength of 10-year exposure specimens are tabulated. Among values of use of lead in construction is the fact that corrosion products of lead outdoors do not cause discoloration of building materials, since they eventually approach the composition of the surface minerals of lead and almost invariably remain on the lead. Maximum permissible fiber stress, density, thermal coefficient of expansion and modulus of elasticity of lead and antimony lead are given. Illustrations include photographs of lead chambers for water-spraying, cooling of sulfuric acid under severe weathering conditions, and various architectural uses.

The Importance of Surface Cleaning for Metal Finishing. G. W. SEAGREN (Mellon Inst.), Corrosion and Material Protection, **3,** No. 1, 6-7, 21-23 (1946) Jan.

Most important single factor de-

termining life of a protective coating is surface preparation of metal, as was proved by bitter experience during the war, when material shipped to the Pacific arrived with only 10 percent of its original paint adhering to goods, in one case. Removal of mill scale and rust, use of inhibitors in final rinse water to prevent corrosion while drying, hydrogen absorption during pickling, and acid electroplating, are discussed.

The Surface Treatment of Hot-Dip Galvanized Coatings Preparatory to Painting and Its Relation to Corrosion Resistance. E. F. PELLOWE AND F. F. POLLAK, Sheet Metal Inds., **23**, No. 225, 82-84, 85 (1946) Jan.

Six methods of surface treatment to improve adhesion of paint on hot-dip galvanized coatings are: natural weathering, mechanical roughening, galvannealing, etching, depositing of lead or copper through metal deposits or black etching, and phosphatizing. Each is evaluated.

The Prevention of Corrosion by the Use of Protective Films. G. OLDHAM, Mining J., **226**, No. 5764, 108-110 (1946) Feb. 9.

A general review of the various methods of surface protection through coatings. Use of oil, paints and enamels, plating, bonderizing, parkerizing, oxide films, galvanizing, spraying, and electrolytic cleaning in preparation for coating are briefly and non-technically covered.

The Navy Develops a New Corrosion-Protection Technique. J. ANTHONY, Iron Age, **157**, No. 15, 104-105 (1946) Apr. 11.

The most significant development to come out of the Navy's new extensive corrosion resistance program is the equipment designed for dynamic humidification of zones of vessels that have been sealed off. This is described and shown. The Navy also has developed a series of preservative materials identified as thin film for coating all unpainted metal parts even in dehumidified areas.

Hot Plastic Paints for Ship Bottoms. R. P. DEVOLUY, C. A. Woolsey Paint & Color Co., Inc., Marine Eng'g & Shipping Rev., **51**, No. 4, 129-131 (1946) Apr.

The Navy hot plastic bottom paint system and its possible use for merchant vessels is discussed. Basic elements of the system, preparation of surface, application of preliminary anti-corrosive and final plastic anti-fouling paint, and effect of atmospheric condition on the application are taken up. Outstanding performance on Navy ships during war has led to consideration of its extension to commercial ship-bottoms. This depends on release of service data by the Navy and on service tests of better quality paints.

New Developments in External Coatings as Corrosion Preventives for Canned Foods. H. R. SMITH, Proc. Inst. Food Technol., 1944, 26-41; J. Inst. of Met. & Metall. Abs., **13**, 16 (1946) Jan.

Solid waxes, water-emulsion waxes, solvent waxes, petroleum products, paints, and alcohol-soluble resin lacquers were tested by means of the continuous salt-spray exposure tests of the Bureau of Standards and by simulated field conditions, to

ascertain their efficacy as external rust preventives for tin cans. Tables are presented evaluating numerically the various preventives tested. Commercial coating problems and Quartermaster Corps specifications are discussed.

Substitutes for Hot-Dipped Tinplate in the Post-War period. K. BRIGHTON, Food in Can, **4,** No. 9, 36, 38, 40 (1944); J. Inst. of Met. & Metall. Abs., **13,** 54 (1946) Feb.

Foods of 20 percent moisture content or higher require enamelled cans if 0.5 percent electrolytic tinplate is used. Electrolytic tinplate will compete with 1.5 percent hot-dipped plate only if corrosion problems are solved so that the savings realized on tin are not cancelled by the cost of enamel. Eventually electrolytic plate of 0.75-1.0 percent tin without enamel may be satisfactory for packers' cans. Bonderized plate probably will not compete with tinplate in general line or packers' cans.

Defects in Anodic Films on Aluminum Magnesium Alloys, Caused by the Precipitation of a New Phase. P. LACOMBE AND P. MORIZE, Etudes sur les Aspects des Pellicules d'Oxydation Anodique formées sur l'Aluminum et ses Alliages, 1944, 33-42; J. Inst. of Met. & Metall. Abs., **13,** 52-53 (1946) Feb.

The appearance of anodic films, obtained on rolled aluminum-magnesium alloy nine percent magnesium after heating at 450° and further treatment at 200° and 240° C., was classified into three groups: (1), where the heat-treatment time is short and precipitation is limited to the crystal boundaries, a general tarnishing is observed; (2), where longer treatment times are given and precipitation occurs in the interior of the grains, a phenomenon described as "maillage" is observed. This is characterized by grey and black mottling which is elongated in the direction of rolling, but which apparently bears no relation to the microstructure of the alloy; (3), when extended heat-treatment times are given, the mottle which is characteristic of maillage is replaced by a uniformly gray or dark film.

Methods of Treating Aluminum and Its Alloys to Prevent Defects in the Anodic Films. J. HERENGUEL, Etudes sur les Aspects des Pellicules d'Oxydation Anodique formées sur l'Aluminium et ses Alliages, 1944, 91-94; J. Inst. of Met. & Metall. Abs., **13,** 52 (1946) Feb.

A detailed discussion of the prevention of the various defects appearing on rolled, machined, and cast materials after anodizing.

Metal Primers—Surface Preparation of Metals. W. J. GRECO, Official Digest Fed. Paint Clubs Amer., No. 234, 115-126; J. Inst. of Met. & Metall. Abs., **13,** 55 (1946) Feb.

A critical review of American papers on anti-corrosive painting.

Preparing and Repainting Outdoor Electrical Equipment. II. E. B. CURDTS, The Narragansett Electric Co., Providence, R. I., Electrical World, **124,** No. 23, 128-30 (1945) Dec. 8.

When galvanizing on the more vulnerable parts of steel-bus structures, and generally on metal, chain-link fences, etc., it is sometimes uneconomical or impracticable to clean the defective areas thoroughly be-

fore painting. The paint chosen should survive a reasonable time over these areas and bond well to adjacent galvanized areas. Paint made with a formula of castor oil and fish oil pigmented with zinc dust and possibly zinc oxide seems well suited.

Repainting of equipment, especially transformers, is discussed. Both the spray and flow methods have their place. The latter is especially good on transformers having complicated cooling surfaces that can not be reached adequately by other means. Special attention should be given to supply equipment and working conditions to facilitate the best paint jobs possible. A form is reproduced which is used to record observations relative to paint conditions. Complete data are recorded on paint jobs.

Electroplating Pipe Interiors. S. G. BART, Bart Mfg. Co., Belleville, N. J., Steel, **118,** No. 25, 96-97 (1946) June 24.

A technique has been developed for electrodeposition of a predetermined thickness of nickel or other corrosion-resistant metals on inside surfaces of pipe, tubing, fittings, etc., to produce a smooth, ductile, pore-free deposit closely adhering to base metal throughout later processing. In one case, a pipe was drawn down to such an extent that the wall was only one-fourth as thick as the original, without rupture of the coating. Used on pipe up to 18 inches in diameter. Process is called Lectro-Clad. Used in a wide variety of plants including power plants, coke and gas products plants, etc.

CORROSION TESTING

Assessing Wear Due to Friction and Corrosion. P. M. FISK, Iron Age, **156;** No. 17, 65-67 (1945) Oct. 25.

Corrosion in door or window hinges may be caused by a combination of causes: (1), electrolytic corrosion between materials; (2), inadequate or poor quality lubrication; (3), scoring due to high spots of metals being more resistant to corrosion than surrounding areas; or (4), intrusion between surfaces of products of corrosion due to atmospheric or other attack, and particles occurring through deterioration of poor coating materials. Two effects normally opposing corrosion are inoperative; namely, accumulation of products of corrosion near the electrode of small cell in electrolytic corrosion, giving rise to conditions leading to reversal of polarity and reduction of further corrosion; and stifling, a process by which corrosion cavities are filled by products of corrosion, thus preventing further entrance of corroding fluid. Motion of the hinge prevents both of these. A special testing apparatus which tests all factors, and puts into operation the complicated variables involved in frictional corrosion of hinges, is described in detail and shown.

Electrochemical Measurements for Corrosion Studies. P. T. GILBERT, J. of Scientific Instruments, **22,** 235-237 (1945) Dec.; Bull. Iron & Steel Inst., No. 123, 55 A (1946) Mar.

A detailed description is given of an apparatus set up to study the behavior of pairs of coupled metals in tap water to establish the relationships between them as they cor-

roded with different concentrations of dissolved oxygen and carbon dioxide in the water. The potentials and corrosion currents from four couples of corroding metals were simultaneously and continuously recorded.

Study of the Dry Corrosion of Metals by Means of a Thermobalance. P. CHEVENARD, X. WACHE AND R. DE LA TULLAYE, Bull. Soc. Chim. France, **11,** No. 5, 41-47 (1944); J. Inst. of Met. & Metall. Abs., **12,** 360 (1945) Nov.

Features of the equipment are: (1), placing of furnace above balance; (2), use of funicular suspension instead of knife-edge; (3), deadening of parasitic oscillation by means of arms dipping into three oil cups; and (4), recording of weight changes on film by light reflected from beam. Experiments on the oxidation of nickel in air from 850° to 1050° C. fit the theory of Dunn ("High Temperature Oxidation of Metals." 1926).

Rust Determination in Presence of Steel. F. GIBALDO, Metal Hydrides, Inc., Iron Age, **157,** No. 16, 58-59 (1946) Apr.

A preferential solvent and its application for the identification and estimation of rust and hydrous ferric oxide in the presence of steel is described. Solubility of the steel in this solvent was found to be 0.1 mg per 100 ml at 68° F. Freshly precipitated hydrous ferric oxide is dissolved in the solvent and quantitatively determined, and a quantity as low as 0.01 mg (as iron) is determined. Additional data are presented to show the effect of solvent concentration on the solubility of rust.

CONSTRUCTION MATERIAL

Durability of Light-Weight Steel Construction. III. Protection of Steel Surface from Atmospheric Corrosion. J. H. CISSEL AND W. E. QUINSEY, Univ. Michigan Eng. Research Bull., No. 30, 333 pp. (1942); J. Inst. of Met. & Metall. Abs., **13,** 16 (1946) Jan.

An annotated bibliography of 1467 references, covering the period 1877-1942 and arranged in chronological order. Author and subject indexes are appended.

FUNDAMENTALS

Controlling Factors in Atmospheric and Immersed Corrosion. W. H. J. VERNON, J. of Scientific Instruments, **22,** 226-230 (1945) Dec.; Bull. Iron & Steel Inst., March, 1946, No. 123, 55 A.

The hydrogen-evolution and the oxygen-absorption types of immersed corrosion are dealt with. In the former type most frequently the obstruction occurs at the cathode and is associated with the phenomenon of hydrogen overpotential. In the latter type there are two well-known controlling factors: an obstructive film at the anode; and the rate of supply of oxygen to the cathode. In atmospheric corrosion the frequently encountered controlling factor is the rate of supply of water. In the case of iron and steel the controlling factor at high relative humidities is provided entirely by the state of purity of the atmosphere. The growth of air-formed oxide films and the significance of rectilinear, parabolic, logarithmic, and asymptotic oxidation-time curves are considered.

Fundamental Investigation of Graphitization of Piping—Progress Report No. 5. S. L. HOYT, R. D. WILLIAMS AND A. M. HALL, Report before ASME Ann. Mtg., 1946; Edison Electric Inst. Bull., **14**, No. 2, 48-50 (1946) Feb.

The present status of the EEI-AEIC investigation of graphitization of piping is summarized. The mechanism and stages of graphitization, effect of deoxidation practice, composition, structure, and heat treatment are discussed. Restoration of partially graphitized joints by normalizing, and pipe materials selected for new installations are mentioned. The latter are one-half percent chromium-one-half percent molybdenum, one percent chromium-one-half percent molybdenum, two percent chromium-one percent molybdenum and one-fifth percent vanadium-one percent molybdenum steels. Use of chromium-nickel-molybdenum has also been proposed.

Oxide Films on Metals. II. Initial Oxide Films on Aluminum. P. D. DANKOV, A. A. KOCHETKOV, AND N. A. SHISHAKOV, Izvest. Akad. Nauk U.S.S.R., (Khim.), 274-285 (1942). (In Russian); J. Inst. of Met. & Metall. Abs., **12**, 358 (1945) Nov.

Electron-diffraction and X-ray analysis, detailed data from which are given, indicate that in the surface oxidation of aluminum by the atmosphere, potassium dichromate, etc., an amorphous oxide layer is first formed; when heated at 200-300° C. for a short time this is converted into cubic gamma aluminum oxide. Contradictory data of previous investigators are due to insufficient care in the preparation of samples.

On the Oxidation of Aluminum. N. CABRERA, Compt. rend., **220**, No. 3, 111-113 (1945); J. Inst. of Met. & Metall. Abs., **13**, 81 (1946) Mar.

The mechanism of the oxidation of aluminum is discussed on theoretical grounds: (1), according to Mott's theory (Trans. Faraday Soc., 1940, p. 472), which is shown to be inadequate; (2), from considerations of thermal energy; and (3), from considerations of the photoelectric effect.

Passivity of Metals. P. LACOMBE, Revue de Métallurgie, Mémoires, **40**, 257-265 (1943) Sept. Bull. Iron & Steel Inst., Feb., 1946, No. 122, 33 A.

The author suggests the following definition of passivity: a metal is said to be passive when, during a chemical or electrochemical transformation, it loses a great deal of its power to emit ions, this emission being suppressed by interposition of a gaseous, solid or even liquid film. There are various methods of producing and destroying passivity; and the existence of a film is the condition necessary for conferring passivity on a metal, but it is only effective when the film is very thin, continuous and adhesive, and of an amorphous structure.

GAS AND CONDENSATE WELL CORROSION

Corrosion of High Pressure Production Equipment. Abstract. F. S. WEST, Paper, API SW. Prod. Div., Shreveport, May 13-17, 1946; Oil Weekly **121**, No. 12, 32 (1946) May 20.

It is estimated that two-thirds of all present distillate fields are corro-

sive. Therefore, corrosion presents a continual hazard to tubing strings, Christmas-tree fittings, flow lines, etc. The investigations of the API, Bur. of Mines and the research organizations of several producing companies on high pressure equipment corrosion are discussed. A method for the inspection of internal tubing surfaces, without killing a well, by the use of an internal caliper inserted into the tubing through the well head when under well head pressure, is described.

Water Analysis in Cycling Fields. Petroleum Engineer **17**, 180 (1946) Apr.

Analyses of duplicate water samples from 14 corrosive condensate fields and 10 non-corrosive fields are reported. Very little correlation between the various analyses has been found to date.

GENERAL CORROSION

Rust Not—Want Not. D. H. KILLIFFER, Scientific American, **174**, No. 4, 161-163 (1946) Apr.

The problems of suppressing rust and corrosion must be solved to relieve the mounting strain on our mineral deposits. Important advances in corrosion prevention forced by the war are briefly summarized, with illustrations from corrosion tests on zinc and combinations of zinc with other metals (galvanic corrosion) and illustrations showing cathodic protection of iron panels in contact with zinc anodes. Inhibitors are briefly discussed and electrolytic action analyzed. A popular article.

German Corrosion Research. Papers before Gesellschaft fur Korrosionforschung und Werkstoffschutz, Korrosion und Metallschutz, **20**, No. 1, 63-76 (1944) Jan., No. 2, 107-113 (1944) Feb.; Metal Progress, **49**, No. 3, 594, 596 (1946) Mar.

Papers briefly abstracted include: one by F. Eisenstecken on recent German research on corrosion of iron and steel, emphasizing need for care in interpreting short-time corrosion tests; paper by W. Machu on electrochemical pore test method for quantitative examination of protective finishes, with special reference to phosphate coatings; paper by E. Baerlechen on heat and corrosion resistant steels for military operations; and papers by H. Bennek and H. Hougardy and P. Schierhold on the chromizing process for treating steel and its application. Such chromized parts are held to have a higher corrosion resistance than 18-8 or 17 percent chromium steel.

Protests a Senate Hearing Record—A Comunication. F. D. FOOTE, Alloys Development Co., Railway Age, **118**, No. 16, 564-566 (1945) Oct. 6.

Inaccuracies and misconceptions connected with corrosion are pointed out in testimony before Special Committee to Study Problems of American Small Business before the Senate, on future of light metals in freight-car construction. The prevalent fallacy that deterioration of coal cars results mainly from corrosion due to sulfur in coal, and misleading statements in regard to costs of aluminum compared with corrosion-resistant, high strength steel, are pointed out and refuted.

INHIBITORS

Inhibition of the Corrosion of Metals in Contact with Water and/or

Steam. W. MURRAY, Assoc. of British Chem. Mfrs., Steam Engineer, **15,** 117-118 (1946) Jan.; Bull. Iron & Steel Inst., March, 1946, No. 123, 55 A.

Recommendations on methods of reducing the corrosion of metals by water and steam are made. Keeping up the pH value of the water and adding tannin is advocated for the prevention of "graphitic wastage" in cast-iron economizers.

Solutions for Keeping Steel Free from Rust. J. RAE, Mfg. Chem., **16,** 394 (1945); Brit. Abs., BI-Chem. Eng'g & Ind. Inorganic Chem., Including Metall., Jan., 1946, 30; Corrosion & Material Protection, **3,** No. 3, 27, (1946) Mar.

Rusting of mild steel can be prevented for more than 12 months by immersion in 70 percent ethyl alcohol (containing 0.15 percent sodium bicarbonate or one percent concentrated aqueous ammonia), one percent solutions of concentrated ammonia or sodium nitrate, or in a 0.1 or 1 percent solution of potassium hydroxide. Twenty-two different solutions were examined.

Amine Type Wetting Agents as Acid Corrosion Inhibitors. J. H. BRESTON, Producer's Monthly **10,** No. 7, 19-22 (1946) May.

Laboratory tests and preliminary field experiments indicate that 10-20 ppm concentrations of alkyl amine acetate wetting agents are effective corrosion inhibitors for dilute acids. Three n-alkyl amine acetates, a coal tar fraction, a substituted glyoxalidine, a rosin amine and a colloidal tetraphosoglucosate showed definite inhibiting properties in hydrochloric acid solutions of pH 2.5—3.0. Tabulated data show the substituted glyoxalidine (cationic amine 220) to give the best results. These inhibitors are more beneficial to steel than to copper or brass and are most effective under oxygen-free conditions.

INSPECTION

How to Locate Corrosion in Refinery Tubes. Petr. Eng., **17,** No. 9, 74 (1946) June.

The Shell Probolog for internal inspection of heat-exchanger tubes made of non-magnetic metal is described. The instrument records changes in resistance as the probe is pulled through the tube. Failures or unusual thinning can be picked up from the chart. This method of inspection leads to salvage of good tubes from defective tube bundles.

Non-Destructive Testing of Refinery Equipment. C. D. HAVENS, Magnaflux Corp., Petr. Eng., **17,** No. 9, 92 (1946) June.

The Magnetic Particle and the Fluorescent Penetrant inspection method for detecting fatigue cracks in refining equipment is described. Detection of such cracks before actual plant failure is of inestimable value. Photographs and descriptions give details of operation and adaptability of the two methods. The Magnetic Particle inspection method is applicable to metals which may be magnetized, and the Fluorescent Penetrant method is applicable to non-magnetic metals.

METAL FAILURE

Relation Between the Cast Structure and the Defect Called "Reticulage" (Revealed by Anodizing Aluminum). J. HERENGUEL, Etudes sur les Aspects des Pellicules d'Oxydation Anodique formées sur l'Aluminium

et ses Alliages, 1944, 43-58; J. Inst. of Met. & Metall. Abs., **13,** 53 (1946) Feb.

Reticulage, consisting of a network of lines forming a more or less neat cellular pattern, elongated in the direction of rolling, marks out the boundaries between the crystals in the original cast structure. Crystal boundaries in the cast structure open up during rolling, and in this respect they differ from the boundaries formed by recrystallization during annealing. The influence of the type of deformation and the grain-size of the material as cast on the defect is discussed. In some appended remarks, N. Belaieff advances the opinion that iron and silicon must be present in the metal before the defect will appear.

Investigations on the Corrosion Behavior of Standard (Secondary) Sand and Chill-Cast Aluminum Alloys. R. STERNER-RAINER, Metallwirtschaft, **22,** No. 36/38, 517-522 (1943); J. Inst. of Met. & Metall Abs., **13,** 12 (1946) Jan.

An investigation of corrosion resistance was carried out on the same alloys and using the same variables as those used by Reschke (J. Inst. of Met. & Metall. Ab., **13,** 12 (1946) Jan.), with the difference that a short-time (18-day) corrosion test was introduced. The specimens were immersed in a sodium chloride solution containing hydrogen peroxide (D. V. L. solution—exact composition not given), and the corrosion products were removed every 24 hours, dried and weighed. The results, given in the form of tables and graphs, show that the highest corrosion resistance was obtained with the binary aluminum-magnesium and aluminum-copper alloys, and with the ternary aluminum magnesium-silicon alloys, though the corrosion resistance was never equal to that of aluminum-magnesium alloys cast from virgin metals. The corrosion-resistance is improved to the greatest extent by the Eloxal surface treatment; heat-treatment decreases corrosion resistance in most cases.

Cavitation Test of Hydraulic Turbine Model. E. STAGE, Teknisk Tidskrift, **37,** 1003-1007 (1945) Sept. 15; Engrs. Digest (Am. Ed.), **3,** No. 1, 31-33 (1946) Jan.

Procedure and formulae for determining cavitation limit of hydraulic turbines are presented, and equipment and an example are discussed.

Classification of the Defects Appearing on the Surface of Aluminum and Its Alloys During Anodic Oxidation. J. HERENGUEL, Etudes sur les Aspects des Pellicules d'Oxydation Anodique formées sur l'Aluminium et ses Alliages, 1944, 19-32; J. Inst. of Met. & Metall. Abs., **13,** 52 (1946) Feb.

The defects appearing on aluminum and its alloys after anodic oxidation are described and their probable causes discussed. Rolled, cast, and machined products are dealt with. Defects such as local attack during anodizing and attack of the dye after dyeing are considered, in addition to those which are inherent in the metal before anodizing.

Investigations on the Corrosion Behavior of Some Secondary Aluminum Alloys. L. RESCHKE, Metallwirtschaft, **22,** No. 36/38, 507-517

(1943); J. Inst. of Met. & Metall. Abs., **13,** 12 (1946) Jan.

The corrosion resistance of a number of standard aluminum casting alloys, cast from scrap material and containing copper, zinc, magnesium and silicon in various proportions, was studied by a three percent sodium chloride spray test and a repeated-immersion test in water (pH 8.5) and by exposure to a chimney atmosphere containing a small amount of moisture and sulfur. A 10-minute exposure per hour for 30 days at 20° C. was used in the former two tests, and the examination included loss-in-weight determinations and macroscopic and microscopic surface examinations. In addition to the effect of composition, the effects of surface finish, surface-protection treatment, and heat-treatment on the corrosion resistance, were also studied. Results are given.

Increasing Fatigue Resistance by Shot Peening. Machinery (London), **67,** 449-454 (1945) Nov. 1; The Metals Review, **19,** No. 1, 16 (1946) Jan.

Shot peening has increased the life of hypoid gears by as much as 600 percent; aircraft engine crankshafts, 900 percent; steering knuckles, 475 percent; welded joints, 310 percent; transmission main shafts, 520 percent; and helical springs, 137 percent. Process in which shot is thrown on work from a centrifugal wheel that revolves at high speed discussed.

Graphitization of Carbon-Molybdenum Steel in High Temperature Steam Piping. G. A. TIMMONS, Climax Molybdenum Co., Paper before ASME, Ann. Mtg., Jt. ASTM-ASME Res. Comm. on Effect of Temperatures on Properties of Metals, Nov. 27-Dec. 1, 1944; Welding J., **25,** No. 1, (1946) Jan.

Graphitization of carbon-molybdenum steel pipe in high-temperature steam installations is considered from the viewpoints of thermodynamic stability and rates of reaction. Graphitization may be expected whenever cementite is present in steel in service under temperatures of 850-1000° F. To date the only positive method of preventing graphitization is to exclude carbon from the steel. This now is commercially impractical; however, by restricting the carbon content to less than 0.06 percent, the amount of graphite that can be formed may be so limited that it would be ineffective. It is proposed that iron base alloys containing less than 0.06 carbon, and alloyed to provide adequate creep strength, be given further consideration as materials for high-temperature steam piping. A complex carbide $(FeMO)_{28}C_6$, may be produced in a low-carbon 0.50 percent molybdenum steel by isothermal transformation of austenite at 1300° F. Some preliminary creep-test data for iron-base alloys containing 0.50 percent molybdenum and less than 0.05 percent carbon are presented.

A Study of Austenitic Welding for Control of Graphitization in Steel. I. A. ROHRIG, Detroit Edison Co., Paper before ASME, Jt. ASTM-ASME Res. Comm. on Effect of Temperature on the Properties of Metals, Nov 27-Dec. 1, 1944; ASME, "Graphitization of Steel Piping," Sept., 1945, 65-76 (on ASME Shelf); Welding J., **25,** No. 2, 90-s-101-s (1946) Feb.

The paper presents evidence that

the formation of dangerous "chain" type graphitization at welds in carbon-molybdenum piping exposed to high-temperature service may be inhibited by the use of austenitic chromium-nickel filler metal. In the tests reported, carbides migrated from the pipe metal adjacent to the weld and were absorbed by the austenitic filler metal, instead of decomposing into graphite in the critical zone at the low-temperature edge of the heat-affected pipe metal. The investigation covered: (a), examination of an 18 percent chromium-8 percent nickel weld between carbon-molybdenum and 18 percent chromium-8 percent nickel pipe after 20,000 hours of service at 925° F., which revealed carbon migration from the carbon-molybdenum pipe metal to the austenitic filler metal; (b), laboratory tests at 1000 to 1200° F., which showed carbide absorption by both 18-8 and 25-20 chromium-nickel austenitic filler metal from both high-aluminum and low-aluminum types of carbon-molybdenum pipe; (c), graphitization tests of welds made in samples of pipe from the Springdale plant of the West Penn Power Company in which graphitization was first observed. A sample welded with carbon-molybdenum filler metal showed incipient "chain" type graphitization whereas a sample welded with austenitic filler metal did not.

Some Notes on Graphitization. L. CROME, Dayton Malleable Iron Co. Foundry, **74,** No. 4, 98-101, 232-233 (1946) Apr.

Due to unusual phenomena experienced in graphitization of malleable iron probably connected with cooling rate in the mold, the effect of chills was studied, using irons responsive to a low-temperature preanneal heat treatment. Experimental results indicated the following: A white iron composition drastically cooled from above 1400° F. will graphitize in a fraction of the time required for slower cooling, and the carbon is distributed in smaller nodules. This phenomenon or a similar one is effective in the whole range between 1400° F. and solidification temperature. Same effect can be accomplished on a slowly cooled casting by reheating and drastically cooling from above 1400° F. If part of the casting cooling faster than the bulk of the metal should cool to just below 1400° F., and then a heat balance be set up so this part is reheated to just above 1400° F., the condition for setting up nuclei by the low temperature treatment is destroyed, and subsequent graphitization retarded in this part. Assuming normal cooling down to 800° F., time in cooling from 800° to 400° has a marked effect on subsequent graphitization rate. Fractures are shown.

Stress Corrosion Cracking of Mild Steel—I, II, III and IV. J. T. WABER AND H. J. MCDONALD, Illinois Inst. of Tech.; Corrosion & Material Protection, **2,** No. 8, 13-22 (1945) Nov.; No. 9, 13-16 (1945) Dec.; **3,** No. 1, 13-19 (1946) Jan.; No. 2, 13-20, 24 (1946) Feb.

A general precipitation theory of stress corrosion is developed which states that high local stresses, induced by the presence of a crack, accelerate the formation of a galvanic cell by accelerating precipitation, and the crack grows by the dissolution of newly formed anodic material. Facts not explained by

previous theories are: (1), stress corrosion cracks are mostly intercrystalline, slightly transgranular and slightly branched; (2), elements in the steel affect resistance to cracking; and (3), cracking is inhibited by cathodic protection, compressive stresses and removal of nitrogen. A free-nitrogen factor which measures the amount of nitrogen available to form iron nitride has been developed. Linear correlations are shown to exist between any two of the following: (a), extent of aging; (b), rate of cracking; and (c), free-nitrogen factor. Steel may be protected from stress corrosion by shot peening, nitriding, cathodic protection, and wet hydrogen treatment. Voluminous bibliography.

Balls and Seats for Pumps. Corrosion and Material Protection, **3**, No. 3, 30 (1946) Mar.

A new abrasion and corrosion-resistant alloy called "Tantung" has been introduced into the oil industry in the form of pump balls and seats. It is a hard, tough, wear-resistant alloy containing tantalum-columbium carbides, is also nonmagnetic and practically unbreakable, with self-lubricating quality. Laboratory tests have proven it superior, and field tests, still running, have shown it four times superior to conventional ball and seat materials now in use. Tests are being conducted in specially selected areas where there are maximum corrosion problems, abrasion, magnetism and breakage. Balls and seats are cast and finish ground to API specifications.

Steel Tower Corrosion Presents a Problem. C. M. LYTTLE, Kansas City P. and L. Co., Electric Lt. and Power **24**, No. 5, 58 (1946) May.

"Close inspection of this steel tower adjacent to a power station (and in the smoke path) disclosed certain tower joints badly rusted (but no general corrosion) with bolts corroded nearly through. The remainder of the tower showed no corrosion. Chemical analysis of the joint deposits led to the conclusion that line charging current flowing through the joints caused the corrosion by electrolysis." Remedy: replacing the corroded members and bonding them to the tower.

PETROLEUM INDUSTRY

Development Work to Prevent Corrosion. B. B. MORTON, International Nickel Co., Petrol. Engineer, **17**, No. 2, 134+ (1945) Nov.

The general course of research projects is discussed, with illustrations from the study of corrosion-resistant materials in the petroleum industry. Examples cited are: development of special sucker rod materials (testing of nickel-plated SAE 4620 and heat-treatable Monel); of non-magnetic drill collars and subs (K-Monel); linings for vessels (stainless steel); materials to resist fraction from crude containing sulfur and naphthalene acids (18-8-molybdenum steel or Inconel); a solution for abnormally corrosive sulfuric acid (high silicon cast iron). The special value of preliminary tests is stressed. Research of importance at the moment is the study of corrosion in condensate wells, carried on by several organizations. Nickel is more widely used against hydrochloric acid due to a discovery by a major oil company.

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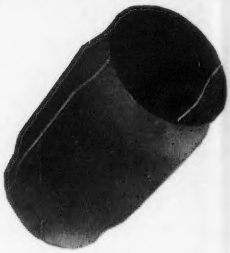

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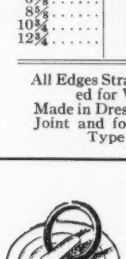

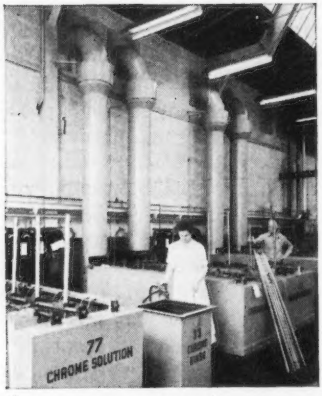

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PIPE CORROSION

Cathodic Protection in the Refinery. D. HOLSTEYN, Shell Oil Co., Petr. Eng., **17**, No. 8, 154-8 (1946) May.

The problem of corrosion prevention in a refinery area is complicated by the existence of a maze of lines of varying size and location. To secure adequate protection, it is frequently necessary to use several ground beds, properly located, with a single rectifier installation, so as to avoid shielding and over-protection.

"From laboratory investigations and experiences from cathodic unit installations, approximately three milliamperes per square foot of bare line are required to produce necessary protective potentials in a soil of about 1000 to 1500 ohm resistivity. For lower resistance soils, current densities of five to 10 milliamperes per square foot of bare pipe may be necessary, whereas one milliampere per square foot may be sufficient for soils of 3000 to 5000 ohm resistivity. If an area is to be placed under cathodic protection, usually the hot spots or corroding areas and soil conditions are known from data accumulated by bell-hole inspections or leak records, or from corrosion surveys. The geographical layout of the underground structures may be obtained from available refinery prints and the area of piping in question may be calculated. If the above-named conditions are known, a rectifier may be designed for the necessary voltage, and current requirements based on the number of anodes used. The rectifiers are sized about 30 percent over the theoretical requirements to allow for increase in resistance of the ground bed due to deterioration and for the expansion of the ground bed, should it become desirable.

"At present there are 26 cathodic units in operation and more installations are to be constructed. The cost per installation varies from $80 to $1200. The average capacity per unit is 10 volts, 50 amperes direct current, which may protect an area of from 10,000 to 25,000 square feet of bare pipeline, depending upon the geographical layout of the lines in the area to be protected and soil conditions. The annual operating cost has averaged $200 per installation per year, including supervision, repairs, renewals to ground beds, and power cost." Results are shown in graphs.

Galvanic Couples and Cathodic Protection. M. C. MILLER, Ebasco Services, Inc., Petr. Eng., **17**, No. 8, 55-8, (1946) May.

Tests were made as to the potential required to stop corrosion of underground pipes. It appears that it is necessary to change the measured potentials of the structure to remote earth or of the electrode near the anodes, so that they are equal to, or greater (more negative) than, the open circuit potentials of the anodes. Therefore, if the maximum open circuit voltage of the anodes likely to be encountered along a specific pipeline in a particular soil could be determined, it could be used as a criterion for protection and probably would be more accurate than using minus 0.8 or minus 0.86 volt now generally used for all conditions.

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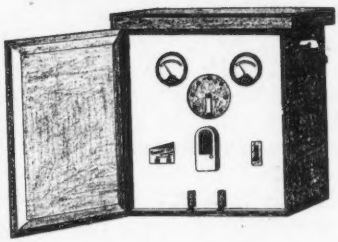

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